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Nutrition of

- ★ Plants
- ★ Animals
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The Principal Problems in Animal Nutrition

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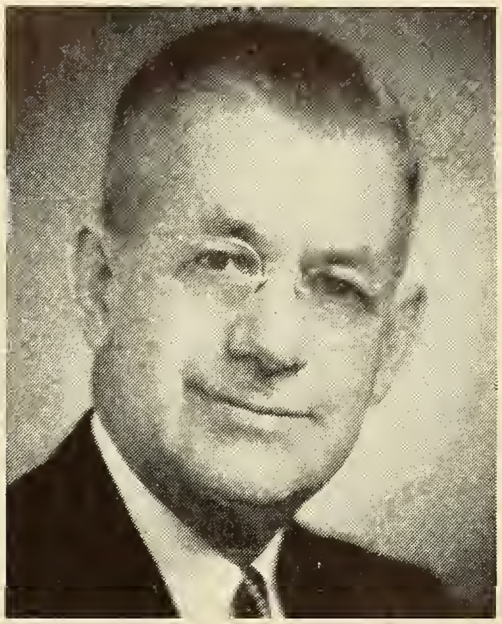

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THE TERM "ANIMAL NUTRITION" is certainly a broad one, even if we restrict its consideration to farm animals. There are marked species differences in requirements which result primarily from differences in the anatomy and physiology of their digestive tracts. While there are problems common to all species, there are specific problems for each one which diverge widely, particularly when one considers the nutritional needs of ruminants compared with non-ruminants. This talk will give major attention to the problems of ruminants because the relationships under consideration in this symposium are both most varied and also of largest quantitative importance in the case of these species.

You are aware that microbial processes in the rumen of cattle and sheep enable them to digest carbohydrates which pigs and chickens cannot. This process results in the synthesis of amino acids and several B vitamins which the non-ruminants must have preformed in their feed. These statements might imply that the nutrition of ruminants is a comparatively simple matter. This, however, is far from true, particularly in so far as economical production is concerned. Because cattle and sheep consume such large amounts of forage and because the nature of this forage, as governed by cultural factors, plays a large role in determining the kind and extent of the microbial activities in the rumen, the problem here concerned bears a special relation to the overall topic of this symposium. Thus, at the outset, I shall discuss some nutritional problems, the solution of which requires a better understanding of rumen processes.

This is an area of research in which Michigan State College has made very large contributions under the leadership of Dr. Huffman. Today we have less knowledge of the science of nutrition as applied to cattle and sheep than we do for pigs and chickens. This situation has resulted, in large part, from our delay in exploiting the initial discoveries regarding rumen processes. In 1884 Tappenheimer in Germany found that large quantities of volatile fatty acids, notably acetic, were produced from cellulose by rumen bacteria and it became recognized that the rumen played an important role in carbohydrate digestion. But it was not until about 1940 that the quantitative studies began which have been responsible for our present knowledge. In 1891 Zuntz showed that rumen bacteria used non-protein nitrogen for their growth, but clear proof that the protein nutrition of the host could be thus served was not produced until 1937. The discovery of Bechdel and associates in 1928 that vitamin B is synthesized in the rumen of the cow was not followed up for other vitamins until about 1940. Since that date rumen research has been very active in all three fields.

CARBOHYDRATE DIGESTION IN THE RUMEN AND ITS UTILIZATION

Quantitatively the most important function of the rumen is the microbial breakdown of cellulose and other higher polysaccharides for which no enzymes are secreted by body tissues. Some of the governing factors of the process have been worked out. We know that starch, as well as cellulose, is broken down and that when large amounts of starch are present the higher polysaccharides are attacked less. There must be a liberal supply of protein or other nitrogen compounds which the micro-organisms can use for their growth. These organisms also require certain special growth

factors, either furnished in the feed or synthesized under appropriate conditions in the rumen. Much additional research is needed, however, to extend present knowledge of the requirements for the maximum breakdown of cellulose and related compounds and, thus attain the maximum utilization of fibrous feeds. Investigations to establish the specific biochemical pathways concerned are a basic requirement.

The carbohydrates that are broken down in the rumen serve the body as a result of the absorption and metabolism of the fatty acids produced. The principal ones are known and the metabolic changes through which they provide useful energy are partially understood. There are others which are formed in significant amounts under certain conditions, the usefulness of which remains uncertain. The production and utilization of these acids need much further study in the interest of learning the extent to which they can serve the body. It is evident that the relative amounts of the various fatty acids that are produced vary with the nature of the feed and other factors that affect microbial action. Further quantitative information is needed here, particularly in view of the likelihood that all are not of equal value to the host.

The most important problem presented by the rumen fermentation of carbohydrates and the metabolism of the products is concerned with the energy relations involved. Carbohydrates serve the body as the principal source of energy. How do the nature and extent of rumen fermentation influence the amount of productive energy available to the body? Approximately 6 percent of the energy of the carbohydrates fermented is lost in the gases formed. An approximately equal percentage, on the average, appears to be lost as heat resulting from the process. The extent and variability of these losses need study as one of the measures of the conditions under which rumen fermentation processes and the feeds concerned can best serve the body. More important, perhaps, there is the question of the energy relations involved in the metabolism of the absorbed fatty acids. Are they all useful sources of energy for current body processes or for fat formation? To what extent is their gross energy lost as heat in the metabolic processes involved? Do the principal ones differ in this respect?

Calorimetry was a very active field of animal nutrition research in the United States during the first three decades of this century. Then activity declined, partly because of the difficulties of the problems and procedures involved, but, more important perhaps, because of the greater attractiveness of research in the field of the "newer knowledge of nutrition." There is a great need for a revival of interest in both indirect and direct calorimetric research for the solution of energy problems presented by the modern knowledge of ruminant processes. We need a greater appreciation of the fact that the largest use of feed by all species is to provide the body's need for energy and that the efficiency with which this need is met is basic to feed selection and to the economy of production.

The *Total-Digestible-Nutrient* feeding standard, which is the one most widely used in this country for evaluating feeds and for setting forth body requirements, is based on the assumption, in so far as carbohydrates are concerned, that a pound broken down to fatty acids and gases has the same available energy as a pound digested to glucose. The widely different nature of the processes involved and of the end products suggests that this assumption deserves much further study.

The question of the relative net energy value of absorbed glucose and absorbed fatty acids also needs attention. In the solution of these questions one may expect to find an explanation as to why a pound of T.D.N. in concentrates has a markedly higher net energy value than a pound of T.D.N. in roughage. The issues here concerned also indicate that an important overall area of research in animal nutrition is the development of a feeding standard which is based on a better measure of the useful energy of feeds than the T.D.N. procedure. Such a standard could be used in both practice and experimental studies. Several others have been proposed and some of them are in use, but critical scientific studies of their comparative value have been few. It is important to bear in mind that a digestion trial merely measures the disappearance of a nutrient in passing through the tract. It does not tell us what is actually absorbed or how useful it is to the body. This fact has special significance in the case of energy metabolism in the ruminant.

A related problem is concerned with the development of chemical measures of the carbohydrate components of feeds which will be more closely correlated with useful energy value than the conventional partition into crude fiber and nitrogen-free extract. This has been a fairly active field of research as is indicated by methods developed for determining cellulose, lignin, "holocellulose," and other fractions. These measures need further attention, particularly as regards their correlation with studies of carbohydrate breakdown in the rumen and with the usefulness of the energy yielding nutrients thus produced. The agronomist has a right to expect information from the nutrition scientist as to criteria he should use in measuring the nutritive value of his crops in terms of the species to which they are to be fed. Such information is an essential guide for the production of the largest yield of utilizable energy and nutrients.

In concluding the discussion of questions related to carbohydrate metabolism in the rumen, mention should be made of bloat, which is a practical problem of large importance. Neither the specific physiological cause nor reliable preventive measures are known, despite much study. Since the disease occurs most commonly in animals pastured on alfalfa or clover, the importance of its solution to the agronomist, as well as to the stock-

men, is obvious. Combined studies by the physiologist, biochemist and microbiologist are needed.

NITROGEN METABOLISM IN THE RUMEN

While the major nutritional result of rumen activity is the breakdown of complex carbohydrates, its role in protein nutrition is also of much importance. Recent research has greatly clarified our knowledge of the processes that take place. It has also served to emphasize the fact that much more needs to be learned in order to take full quantitative advantage of the microbiological processes that result in a net increase in protein to serve the host's needs. It is now understood that these processes involve both anabolic and catabolic reactions in so far as the protein and other nitrogenous compounds in the feed are concerned. Feed protein is broken down to ammonia and fatty acids, presumably through amino acids. Amides and other non-protein nitrogen compounds are also broken down with the formation of ammonia. Micro-organisms use the catabolic products as sources of nitrogen to build protein during their growth. This microbial protein in turn serves the host as a result of intestinal digestion. These processes explain how urea and other non-protein nitrogen compounds can serve in the protein nutrition of ruminants. The problems awaiting solution center around the question as to how the synthesis of microbial protein in the rumen can be promoted to a maximum.

At the ammonia stage there is always the possibility of loss of feed nitrogen, both from protein and from other nitrogenous compounds, through the absorption of the ammonia. The accumulation of ammonia in the rumen and its consequent absorption is greatest where conditions are least favorable for the growth of micro-organisms for synthetic purposes. This is an important area for further study. The proportion of non-protein nitrogen compounds that can be effectively utilized for meeting the host's protein needs depends upon the extent of this synthetic action. Amides, notably urea, are rapidly broken down to ammonia which may be partially lost through absorption. With large intakes and conditions that are unfavorable for rapid microbial growth, this absorption may take place so rapidly and so extensively that toxicity results. The limitations as to the amount of urea that can be used effectively and safely, in view of the rapid formation of ammonia, have been responsible for studies with other sources of non-protein nitrogen, notably various commercially ammoniated products. These products need much more thorough study before the extent of their usefulness can be evaluated.

Through the medium of microbial synthesis the host is provided with all of the different essential amino acids required for its metabolism, irrespective of the supply in the feed. From the limited studies to date it seems unlikely that the biological values of the mixtures thus provided vary markedly with the nature of the feed or of the microbial activity, but this is a question that deserves further investigation. An analytical tool that needs further application here, and also in other studies of nitrogen metabolism in the rumen, is a quantitative method of distinguishing between the nitrogenous constituents of the feed and those of the bacteria.

A majority of the studies that have dealt with the usefulness of non-protein nitrogen for animal growth and production have been of short duration and/or have not included specific measures of protein nutrition, such as nitrogen balance studies. Further, more critical experiments should be helpful to provide us with additional quantitative data regarding the feed and rumen conditions under which the largest and most economical use can be made of the rumen activities that are related to the protein nutrition of the host. A consideration of the fact that, in the rumen, feed protein is in part broken down to acids and ammonia that may be absorbed, while new protein is formed from non-protein nitrogen, raises questions as to the significance of digestible protein as it is commonly determined. Can a better method of measuring losses in digestion be developed than the conventional one which applies the factor 6.25 to both the feed and feces?

The metabolism of nitrogenous compounds in the rumen and of the absorbed products in the body constitutes a further reason for studying the overall energy economy of rumen processes. Of course, it is understood that urea provides no useful energy and should not be considered in calculating T.D.N. or any other measure. But the metabolic processes may result in more or less energy lost, depending upon conditions. In view of the high energy requirement for urea formation from ammonia in the liver, the more extensive the ammonia absorption, the greater the energy loss, whether the urea is excreted or recycled. In fact, it could be larger if the latter were extensive.

A review of the studies on nitrogen metabolism in the rumen, in comparison with those on carbohydrate breakdown, indicate that the conditions which favor both processes are not identical. For example, a ration high in starch provides an easily available source of energy for micro-organisms to synthesize protein rapidly, whereas cellulose is less readily attacked by organisms in rations high in starch. This fact suggests that, in terms of learning how rumen processes can best serve both energy and protein nutrition, experiments which include observations on both in the same study would be worthwhile.

VITAMIN ACTIVITIES IN THE RUMEN

While it may be considered true as a generalization that the metabolic needs of ruminants for the various B vitamins can be met adequately by rumen synthesis and thus are not required in the feed, recent evidence suggests that this generalization may not be universally applicable. Marked variations in the extent of the synthesis of some of the vitamins in accordance with

changes in the ration have been reported. In considering the feed requirements for the optimum functioning of the rumen with respect to carbohydrate breakdown and protein synthesis, some check should also be made on the adequacy of vitamin synthesis. A special case where vitamin synthesis, both for microbial growth and also for the needs of the host, is governed by the nature of the feed is presented by the dependence of vitamin B_{12} synthesis on an appropriate supply of cobalt in the ration. There are other possibilities regarding the relation of mineral intake to vitamin synthesis in the rumen that deserve investigation.

MICROBIOLOGICAL STUDIES OF RUMEN FUNCTION

It is obvious from the previous discussion that the adequate and economical nutrition of cattle and sheep depends to a very large degree upon providing the micro-organisms of the rumen with the nutrients that they need for maximum growth and activity. This fact points up the importance of the microbiological approach, as well as the animal and biochemical approaches, to the solution of the problems involved. The microbiologist has learned that specific kinds of bacteria are required for specific rumen processes, and that the kinds and numbers are influenced by the feed. Most of the work to date has been descriptive in nature. More quantitative information is needed regarding the different organisms present under varying conditions, how they function in terms of the nutritionally important rumen processes, and just how the situation is altered by dietary factors.

The increasing practice of feeding antibiotics to calves and lambs for the promotion of growth, an effect that seems to be due primarily to influence on the bacterial flora of the intestine, raises important questions as to how the synthetic functions of rumen microorganisms may be affected. Comparatively little work has been done in this area. There have been reports that the feeding of antibiotics increases the digestibility of dry matter and, on the other hand, that activities of certain cellulose splitting organisms are decreased. It has been reported that the activity of organisms that synthesize vitamin B_{12} is lessened by antibiotics, but there is also some evidence to the contrary. *In vitro* studies have shown that antibiotics can decrease the utilization of urea for protein synthesis. These various observations indicate the importance of further studies in this area as a part of investigations designed to determine the place of antibiotics in the feeding of young ruminants.

It is clear from the previous discussions that the problems of the rumen are highly complex and interrelated. It is evident that the status of the nutrients at any moment represents a balance governed by various factors, such as catabolism, synthesis, introconversions and absorption, and that the extent of these processes is determined by the kind and amount of microbial activity. The complexity of the situation should not deter us from trying to solve the many specific problems concerned. As more information is gained, the animal scientist will be in a better position to advise the agronomist as to the specifications which forage and other crops should meet for the greatest usefulness in animal production. I know that the agronomist has been calling for this information for a long time. It is the obligation of the animal scientist to supply it as rapidly as possible. In so doing he will contribute to a further understanding of the soil, plant and nutrition relationships that will in turn result in more efficient animal production.

MINERAL INTERRELATIONSHIPS

The discoveries during the last two decades that forage grown in certain areas is far too low in certain trace elements to maintain animal health and production, and the correction of these deficiencies, either by fertilization or by ration supplementation, have been one of the outstanding developments of animal nutrition research. These discoveries have also served to focus our attention on the fact that we need to know much more about the quantitative requirements of several elements now known to be essential for various species and functions. There are others that regularly occur in the animal body and also in feeds that need critical examination as possible essentials.

Such studies should not be limited to the growth and production measures commonly used in feeding experiments. In such experiments partial deficiencies may not become evident unless the studies cover a substantial part of the productive life. We need more exact criteria of the physiological need and adequacy of a given element. This calls for metabolic studies to determine just how the element functions, with the hope of obtaining biochemical evidence of adequacy or inadequacy. We know, for example, that a deficiency of copper results in anemia and in certain physical symptoms. These symptoms are not specific. We identify copper deficiency symptoms by administering copper to alleviate the deficiency; in this way we arrive at the quantitative amount that is effective. We know that the element is essential for hemoglobin formation, and we know that it functions in certain enzyme systems, but more specific knowledge should result in more specific criteria for detecting its deficiency and for establishing body requirements.

In addition to data on requirements, we need much more information regarding absolute or relative excesses that may be harmful. Molybdenum is a case in point. Forages containing .002 percent, or even less, have been found highly toxic to cattle, but much higher levels can be tolerated where the intake of copper is increased. This means that neither the tolerance for molybdenum nor the requirement for copper is an absolute value but depends upon the amount of the other present in the ration. An excess of molybdenum also interferes with

phosphorus metabolism. Although zinc is an essential element, if consumed in excess quantities it can result in anemia which in turn can be corrected by feeding a considerably larger amount of copper than normally needed. Such interrelationships are not limited to the trace elements. The calcium level influences the requirements for phosphorus, magnesium and manganese, and the toxicity of molybdenum. These are merely examples showing that the requirements for various mineral elements are relative, not absolute, and are cited to indicate that here lies a very important field for further research. This is a very active field of research in several laboratories, but the magnitude and complexity of the problems involved call for a much larger participation of investigators, utilizing all the available knowledge and techniques that may help in arriving at the answers.

Some questions presented by recent findings regarding inorganic sulfur deserve mention. Formerly it was thought that the nutritional importance of this element was limited to its essentiality as a constituent of the sulfur-containing amino acids. Now it is known that the inorganic form can be used by the body to make chrondroitin sulphate, a constituent of cartilage, and, more important, that this form can be used by the rumen organisms to synthesize the sulfur-containing amino acids. It has also been shown that, in certain areas, the level of inorganic sulphate in the forage plays a role in the copper-molybdenum interrelations. What practical importance these various findings may have remains for further study.

Obviously the solution of these various mineral problems is of special importance in the case of animals that depend so largely on forage for their feed, and thus to those concerned with the production of this forage, because soil-plant relationships are involved. In the studies of copper deficiency in grazing animals in Australia, New Zealand and Florida, for example, some of the symptoms reported are alike and some different. The stockmen might ascribe the variable results to the differences in species and breeds of the animals concerned, but the explanations are being found in the variations in the mineral relations, apart from copper content, in the forages grown in these various areas. This particular problem, which needs much further attention, illustrates the fact that studies dealing with the requirement of a specific mineral must take account of the relationships of various others.

This specification can best be met, of course, by the use of purified diets. Important studies with such diets are in progress and should be extended, for very valuable basic information is being obtained. The value of carefully controlled studies with rats, guinea pigs and rabbits should not be discounted. Obviously, however, the final answers must come from experiments with the farm animals in question consuming rations based on the kinds of feed they normally eat in practice. The value of the results will depend upon a critical control of the rations fed in so far as the nature of the ingredients permit, and upon having a detailed description of the mineral and other nutrient relations of the feeds used and of the cultural factors involved. Whatever the study, it is important that measures of performance be not limited to growth, nor to production over any short period, nor to evidence of gross symptoms of deficiency. Growth and appearance may be normal, yet the result may be injuries to tissues and functions that become cumulatively more severe with time. Appropriate biochemical and pathological studies are required to detect this evidence of malnutrition.

There is a strictly biochemical approach to a solution of these mineral problems that is providing important basic information and which should be extended, particularly as it relates to the trace elements. Here I refer to the study of the enzyme systems in which these trace elements function as constituents or catalysts. It is not believed that molybdenum, known for some time as an essential mineral for plant grown, is also essential for animal metabolism, as a constituent of the important liver enzyme, xanthine oxidase. Copper is a constituent of at least four enzymes, which explains its essentiality and provides a basis for studying its adequacy. In addition to being essential constituents of one or more enzymes, trace elements also serve as activators of enzyme systems. Frequently, more than one can serve for a given system. For example, arginase can be activated by either copper or manganese, or iron or nickel. Serving as an activator does not prove essentiality, but where more than one can activate a given system certain interrelations as regards body requirements are indicated.

There is evidence that the explanation as to why antagonisms occur between trace elements, as indicated by those for copper and molybdenum and for copper and zinc previously mentioned, lies in the competition between the elements in question for the same enzyme substrate—an action similar to that of antivitamins. Today, the roles of minerals in enzyme systems and the antagonisms and interrelationships here concerned are being effectively studied by means of *in vitro* experiments with specific systems and minerals. They also are being investigated in animal experiments in which the effect of specific dietary variables on enzyme activity is being investigated with organ and tissue samples obtained by biopsy or upon slaughter. The expansion of these studies should serve to accelerate the accumulation of knowledge as to quantitative requirements and interrelations. As a part of these biochemical approaches, we also need systematic studies of the trace element content of organs and tissues in relation to their enzymic processes.

A practical reason why we need more specific information as to trace element needs and interrelations is to check on the soundness of the increasing practice of adding mixtures of several of them, frequently free choice, to rations in general, purely as an insurance

measure. Not only is this wasteful in many cases, but in some it may be definitely harmful as a result of imbalances thus created.

SUMMARY

In this talk I have discussed only a few of the many problems which might be listed for the field of animal nutrition. In choosing specific ones for consideration I have had in mind the overall topic of this symposium. I hope that the discussions have served to indicate that solutions are needed for important problems that have significant bearings on crop as well as animal production, and that there are promising new approaches to their solution. There is a large need for the expansion of animal nutrition research in general. Nevertheless, I believe that the advancement of knowledge in the field can also be served more effectively by constant consideration as to how we should redirect our research in the light of new facts as they appear and how we can make the most effective use of the new techniques of basic science which are constantly becoming available to us.

Finally, I should like to emphasize the fact that effective programs for the solution of several of the problems here discussed call for the cooperation of soil, plant and animal scientists, in the planning and conduct of the studies and in the interpretation of the results. I am sure that this symposium will result in an increased recognition of the need for this cooperation and its further promotion accordingly.

Nutritive Values of Crops and Cow's Milk as Affected by Soil Fertility[1]

DR. S. T. DEXTER, Professor in the Farm Crops Department at Michigan State College. Dr. Dexter formerly headed the Department of Sciences at Minnesota State Teachers College. His graduate and undergraduate work was done at the University of Wisconsin.

The Research Problem and Procedures Nutrition Project, Kellogg Farm

By S. T. Dexter
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INTRODUCTION

DURING THE PAST TEN YEARS, several members of the Department of Soil Science, Farm Crops, Dairy, Foods and Nutrition, and Agricultural Chemistry at Michigan State College have been engaged in an extensive nutrition experiment dealing with the relationships between fertility of the soil and the nutrition of dairy cattle. Briefly, a 210-acre badly depleted farm was obtained. Part of this acreage was limed and heavily fertilized, while the rest was left in its depleted condition. Crops grown on the two areas were fed to two matched herds of dairy cattle and the milk was fed to rats.

In presenting an introduction to this experiment on behalf of the research group, I would like to review some of the initial thinking that led to this experiment. Before proceeding further, we should acknowledge that, in 1944, the American Dairy Association and the National Dairy Council were interested in sponsoring some research project dealing with milk and dairy cattle. Without their considerable interest and financial help, it is doubtful that such an ambitious 10-year research project with dairy cattle could have been attempted.

Focus Importance of Project

The importance and pertinence of the project may be brought into focus by a brief summary of the dairy business and ruminant nutrition. Roughly speaking, the census shows 30 million dairy cattle in the United States, valued at about $5 billion. Dairy cattle, beef cattle and sheep, (the three major ruminant groups on our farms), provide an annual farm income of about $12 billion, and consume the crops from something like one-half or two-thirds of our crop land. In several states, the dairy business furnishes by far the greatest single item of agricultural income and in a few it provides more income than all other agricultural sources combined. In fact, it would be no exaggeration to state that in the U. S. a major proportion of our land is used in producing crops that are consumed by ruminants.

Ruminants such as dairy cattle, beef cattle and sheep, in contrast with non-ruminants such as swine, fowl and man, are notable for their consumption and digestion of roughages, and for their lack of sensitivity to the quality of protein or the absence of various vitamins in their diet. In rumen digestion, micro-organisms can convert even urea into useful proteins, and can synthesize various vitamins in large amounts. The non-ruminants are comparatively lacking in these abilities. In planning this experiment 10 years ago, it was necessary to face these facts squarely and we wish to reemphasize them now. This has been an experiment dealing with ruminant nutrition primarily, in which the secondary product, milk, was fed to non-ruminants as a measure of its value. This seems particularly pertinent, since the greatest proportion of our highly depleted and infertile land is used in growing feed for cattle, whose milk is used by non-ruminants. Hay and pasture growing on soil of low fertility are the main sources of feed for many cattle. The quality of their milk is a matter of interest to us all.

Another point that was of importance in the initial discussions should be mentioned. In agricultural practice, it is common for the offspring of dairy cattle to live for several generations on the feeds produced on

[1]Supported in part by a grant from the National Dairy Council on behalf of the American Dairy Association.

a single farm, because farmers usually raise their own heifers to maintain the herd. Since the cow's ration is generally composed almost exclusively of hay, silage, pasture and grains produced on the home farm, the results of nutritive defects in the ration may accumulate. Her calves and in turn their calves may show increasing signs of nutritional deficiency as time proceeds. When a cow, or any other animal, is brought into a new nutritional situation, the carry-over from the previous diet may be considerable. Thus, in this experiment, we wished to raise several generations of calves, if possible, and to permit the development of deficiencies, much as they might occur in ordinary practice.

Crop Rotation

In planning the crop rotations, another point received considerable attention. It was intended to provide feeds for the cattle so that the rations of both herds were fully adequate in energy, protein, vitamins, minerals, etc., in so far as our present information would permit. In a good many nutrition experiments, animals have been fed on one crop species only, or have been fed rations obviously deficient in quality or quantity or both. This criticism and the ordinary problem of "empty stomach" disease in animals on infertile soils were recognized and avoided in the initial planning.

It was anticipated that certain deficiencies might arise in the course of the 10-year period, and that they might be clearly defined and established as existing in one ration or the other. For example, one might anticipate a lack of phosphorus in the ration from the depleted soil, and perhaps a lack of manganese in crops grown on the limed and fertilized soil. In both rations, we feared that a deficiency of vitamin A might develop. In any case, should such deficiencies develop, it was the intention, after they were clearly identified, to correct them by the addition of highly purified chemicals to the ration. Later reports will show that this was rarely necessary.

One last point in the initial planning should be mentioned. From the standpoint of agricultural practice, the cropping system was initially recognized as economically impracticable. Since this was specifically a nutrition experiment, all due effort was made to prohibit the entrance of economics into the picture. To avoid all possibility of impertinent economic interpretation, it was determined that accurate or detailed records of yields per acre would not be kept.

THE FARM

A 210-acre farm, located near Battle Creek, Michigan, was obtained. The land was gently rolling, of quite uniform Fox sandy loam and of a fair inherent productivity. In the course of over 100 years of farming it had been badly neglected in soil management until it was highly acid and depleted to a low state of fertility. The pH of the soil was about 4.7. Tests for

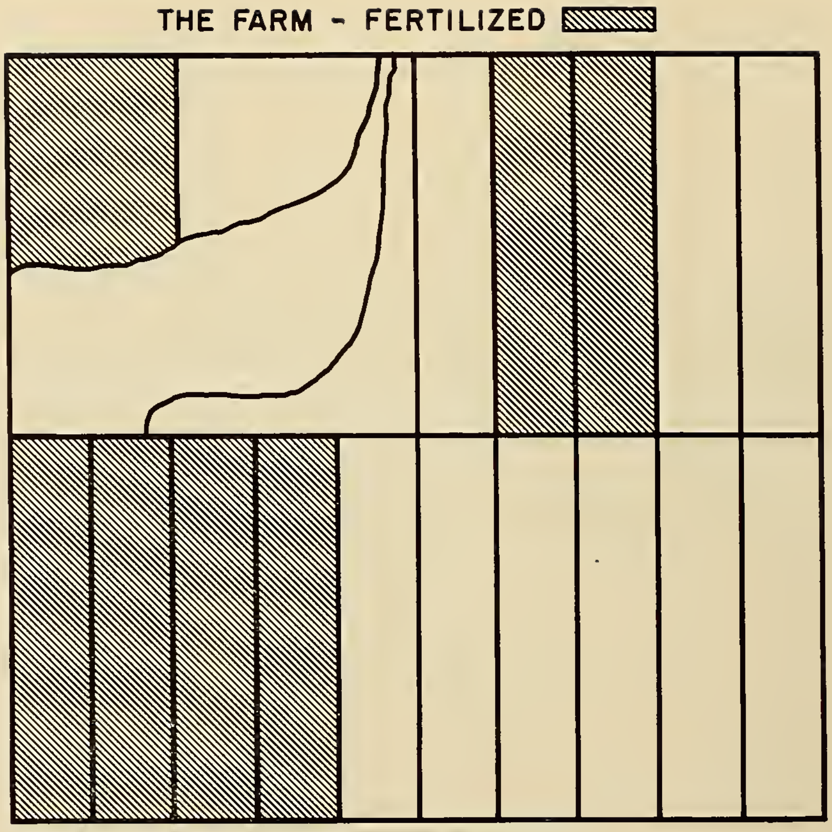

Figure 1.

phosphorus and potassium placed the soil in the "very low" fertility group. Most of the farm had been abandoned for agricultural use, and had not produced a crop in the past 25 years.

Two or three of the fields next to the roads had received fertilizer in the form of barnyard manure in long-past years, and were frequently leased to neighbors for cash-crop farming, since these fields were still capable of producing a crop of economic value. Most of the area had grown up to a sparse crop of weeds, largely sheep sorrel. As nearly as can be learned, no lime or commercial fertilizer has ever been added to the soil.

For the nutrition experiment, the farm was divided into 18 fields (*figure 1*) of 10 acres each. Seven of the fields including the fields next to the roads were limed with 3 tons of lime per acre in 1945 and 3 tons more in 1948. An initial application of 2,000 pounds per acre of 3-12-12 fertilizer preceded any planting. To guard against any deficiency of minor elements in the crops grown on the fertilized fields, adequate amounts of boron, cobalt, copper, maganese, magnesium and zinc were added. Subsequent analyses indicated that the addition of these minor elements was unnecessary on this soil, although it was highly deficient in phosphorus, potassium and nitrogen. In 1948, three years after the addition of the first 3 tons of lime per acre, the pH was found to be about 5.7 and the fertilized area was rated, by chemical test, as "medium in fertility."

The remaining 11 fields were not fertilized with mineral fertilizers or minor elements, but nitrogen in the form of ammonium nitrate or urea was used on the grass crops in order to induce enough growth to make

harvest possible. As a result of the additional growth, it was anticipated that there might be some dilution of most of the minerals in the plants.

LIMITATION IN THE CHOICE OF CROPS

The dairy nutrition experts in the research group were insistent that identical species and varieties of crops be grown on both depleted and fertilized soils, to provide similar or comparable rations for the two groups of cattle. Since alfalfa and clover will not grow on the acid, depleted soils, grass hays were necessarily grown. For the first season, oat hay was grown while getting grass meadows established. Although experience had shown that soybeans produced poorly on this soil, even when fertilized, this crop was grown to provide a grain high in protein. Corn, winter wheat and oats were grown to provide insurance against the loss of a grain crop in any season particularly unfavorable at any one time of year. Thus, a reasonably representative mixed ration was grown, in which the only serious limitation was the necessity of growing a grass hay rather than clover or alfalfa.

MANAGEMENT OF THE ROTATION

During the 10-year period, several slight modifications of the rotation were made, generally for the purpose of assuring better seedings of the grass crop. Experience showed that on the depleted, acid and droughty soil, grass seeded in the fall in winter wheat gave better stands than those obtained by seeding in the spring in oats. Timothy was found to establish productive meadows more quickly than smooth brome grass, and was used in the last few years in mixture with brome grass.

TABLE 1—The seven fertilized fields were planted to the crops shown each year. The various crops rotated on each individual field as shown from 1 to 7

1. Oats, 800 pounds of 0-12-12 in the seedbed. Topdress with 20 pounds nitrogen.
2. Wheat, seeded to grass. 300 pounds 3-12-12 at seeding and 20 pounds nitrogen, as ammonium nitrate or uramon, topdressed in spring.
3. Grass hay, 200 pounds 3-12-12 and 60 pounds nitrogen topdressed in spring.
4. Grass hay, 60 pounds of nitrogen topdressed in spring.
5. a. Grass hay, 300 pounds 0-12-12 and 60 pounds nitrogen topdressed in spring.
   b. Soybeans, 200 pounds 0-12-12 in seedbed and 100 pounds with seed.
6. Corn, 200 pounds 0-12-12 in seedbed, 100 pounds 3-12-12 with seed and 40 pounds nitrogen sidedressed in last cultivation.
7. Soybeans, 200 pounds 0-12-12 in seedbed and 100 pounds with seed.

TABLE 2—10 unfertilized fields were planted to the crops shown each year. The various crops rotated on each individual field as shown from 1 to 10. The eleventh field was continuously in hay

1. Oats, topdress with 20 pounds nitrogen as ammonium nitrate or uramon.
2. Wheat, seeded to grass. Topdress with 20 pounds nitrogen.
3. Grass hay, topdress with 60 pounds nitrogen.
4. Same as number 3.
5. Same as number 3.
6. Same as number 3.
7. a. Same as number 3.
   b. Corn, sidedress with 40 pounds nitrogen.
8. a. Wheat, topdress with 20 pounds nitrogen.
   b. Soybeans, on the corn stubble.
9. Corn, sidedress with 40 pounds nitrogen.
10. Soybeans.

For several years the rotation given in *table 1* was used with considerable success on the fertilized fields, while that in *table 2* was used on the unfertilized area.

Table 1 shows that something over a ton of 0-12-12 fertilizer was added to each acre in the course of a full 7 year rotation. When the initial application of 2,000 pounds per acre is included, the total application per acre in the 10-year period is found to be somewhat over 5,000 pounds per acre. In addition to this, nitrogen was added and some muriate of potash that is not shown in the table. It was anticipated that difficulty would arise from volunteer clover on the limed and fertilized fields, and preparations were in mind to control this difficulty with spray treatments. Actually, this was a minor complication, presumably because of the long period during which no such crops had grown on the farm. The use of nitrogen top-dressing each spring on the grass meadows was undoubtedly a further deterrent to invasion by clover. On the fertilized soil, the hay crop reached maturity and was cut before that on the unfertilized soil. The maturity of the corn crop was similarly delayed on the unfertilized soil.

Table 2 shows the rotation on the unfertilized area. In this rotation, 45 acres of hay, with an additional 10 acres from the field continuously in hay, was required to provide hay for the herd, in contrast to 25 acres on the fertilized land. Fifteen acres of wheat were grown each year, rather than the 10 on the fertilized soil. An extra 5 acres of corn were grown on the unfertilized area, but the acreage of soybeans was the same for the two areas.

There has been a small surplus of grain from the fertilized area, but, in general, the two areas performed their function of feeding the two herds without either lack or great excess of feed. Because the two

TABLE 3—The total acreage and approximate production of crops on the 70 fertilized acres in the 10-year period, together with the approximate removal and addition of fertilizer elements in that time

Crop	Acres	Production	Pounds of fertilizer elements removed in 10 years			
			Phosphorus	Potassium	Nitrogen	Calcium
		lbs.	*lbs.*	*lbs.*	*lbs.*	*lbs.*
Hays......	280	980,000	1,870	15,060	12,040	2,450
Corn......	120	250,000	800	800	3,620	40
Soybeans..	145	60,000	400	1,030	......	114
Oats......	80	100,000	380	440	2,040	67
Wheat....	75	125,000	510	470	2,150	48
Total removed	700	1,515,000	3,960	17,800	19,850	2,719
Total added...	......	....	19,400	40,000	19,000	300,000

herds were considerably different, at times, in the proportion of heifer calves produced, the numbers of animals to be fed in each group were not always identical, and various adjustments in retaining or discarding animals were obviously necessary.

During the past year, part of the hay crop was put in and fed as grass silage. Corn, for silage, was substituted in the rotation for oats, and was followed by wheat.

By the rather free use of Prof. Duncan's chemical analyses, and by estimates of the crop production throughout the period, the figures in *table 3* have been obtained, to give an idea of the removal of various nutrients from the fertilized area in the 10-year period. From our records of use of fertilizers on the fields, we can compute the addition of nutrients. In the course of the 10 years of harvest, the estimate shows almost a million pounds of hay and a half a million pounds of grain produced on the fertilized area. The total removal of phosphorus was approximately 4,000 pounds, whereas over 19,000 pounds were added. Similarly, the crops removed contained about 18,000 pounds of potassium and 40,000 pounds were added. Thus, appreciably more of these elements was added than was removed. In the case of nitrogen, the balance sheet shows that about as much was added as was removed in crops, if we assume that the nitrogen removed in the soybeans was atmospheric nitrogen, fixed symbiotically. The addition of calcium was 100 times as great as the removal.

The applications per acre of nitrogen on the depleted soil were the same as those on the fertilized soils. Since the percentage of nitrogen in the crops was much the same on the two areas and the yield per acre was much less on the depleted area, it would appear that more nitrogen was added to the depleted soil than was removed by the crops. Comparatively speaking, the crops on the unfertilized soil received abundant supplies of nitrogen while having deficient supplies of phosphorus and potash. The response of the crops on the depleted soil to the added nitrogen was remarkably great, particularly in the case of the grass hay. Without nitrogen, the growth was so short and thin that it virtually could not be harvested with ordinary farm machinery.

Table 4 shows the rainfall, by months, for the 10 years, 1945-1954.

In the papers that follow, details will be given concerning other phases of the experiment, but it is appropriate to review these phases briefly now. The original herd of cattle was composed of seven pairs of half-sisters. One animal from each pair was assigned to the ration from the fertilized or unfertilized land. Subsequently three additional pairs of half-sisters were similarly added to the herd. The herd has been fed in the barn the year round. The feed intakes and milk produced have been weighed and recorded daily, and periodic samples of feed, milk and blood have been taken for chemical analysis.

In the past 3 years, cows that have completed at least three lactations on the feeds from the nutrition farm have been placed on another ration, in which the

TABLE 4—Inches of precipitation by months at the Nutrition Farm for the period from 1945-1954 inclusive (furnished by C. M. McCrary)

	Yearly	January	February	March	April	May	June	July	August	September	October	November	December
Normal................	34.10	1.98	1.67	2.45	2.53	4.05	4.07	2.53	3.90	3.14	3.36	2.63	1.92
1945....................	35.07	.61	1.23	2.54	3.15	7.69	3.70	2.14	2.06	5.49	2.18	2.61	1.67
1946....................	30.36	1.77	1.65	3.19	1.27	4.92	1.59	.25	1.62	4.45	3.53	3.16	2.96
1947....................	40.44	2.87	1.09	2.01	7.71	4.79	3.83	2.53	4.94	4.91	1.23	2.77	1.76
1948....................	34.23	1.33	2.30	5.09	3.97	5.79	2.41	2.67	1.22	3.20	.51	2.85	2.89
1949....................	35.23	3.61	2.71	3.39	2.32	2.69	4.12	2.61	3.58	2.83	2.73	1.87	2.77
1950....................	42.24	4.02	3.52	3.28	7.93	.92	4.90	4.70	1.57	5.90	.66	2.29	2.55
1951....................	38.12	2.61	1.64	1.92	3.83	2.89	4.02	3.14	4.01	3.67	4.60	3.25	2.54
1952....................	30.23	2.05	1.58	1.61	3.23	5.51	2.26	4.76	3.04	1.23	.22	2.95	1.79
1953....................	26.23	1.53	.75	2.14	2.73	3.20	4.39	2.79	2.90	1.38	1.89	1.46	1.07
1954....................	41.53	1.66	2.66	2.65	3.38	.94	8.34	2.70	3.31	2.98	8.67	2.51	1.73

grass hay was replaced by a so-called "Kellogg" hay. This hay, a mixture of alfalfa and smooth brome grass, was grown on the nearby Kellogg Experiment Station on soil limed, fertilized and managed for about 25 years in a manner conducive to improved soil fertility. Nine cows in all, eight of them from the herd assigned to the unfertilized area, have been available for use on the "Kellogg" ration. As before, records of feed consumption, milk production, etc. have been kept.

Samples of the milk have been saved, refrigerated, and in some cases composited for feeding experiments with rats in comparison with a standard control diet.

Chemical studies of the soil were made at the beginning of the experiment, and have been repeated since that time. A greenhouse experiment with soil from the two areas has been carried out with many analyses of plants and soil. Occasional detailed chemical studies of field-grown plants have been made. In all, thousands of chemical analyses of soil, feeds, milk, and blood have been made.

SUMMARY

This has been, then, primarily an experiment in dairy cattle ruminant nutrition, in which the milk was fed to rats, non-ruminants, as a measure of its nutritive value. At no time has the project been considered as an experiment relating to the advisable or customary use of fertilizers, crops or livestock. Both herds of cattle have received an abundance of feed, with no regard to soil fertility or yield per acre. All economic interpretations have been avoided. We are unprepared to interpret our findings concerning the nutrition of dairy cattle that were fed crops from depleted or fertilized soil in terms of human nutrition on such crops. The objective of the experiment has been to determine the effect of soil fertility on the nutritive value of crops, as fed to dairy cattle, in terms of the health, reproduction, and milk production of the cows and their offspring, and the growth of rats to which the milk was fed.

From this brief survey of the project, it is hoped that a reasonably clear picture of the experiment as a whole may be gained. This may provoke early discussion and lead to the formulation of pertinent questions, that may or may not be answered in the more detailed discussions that will follow. On behalf of the local research group, and, I am sure, the invited speakers, questions and discussion are invited.

Influence of Environmental Factors On Plant Composition

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As THIS SYMPOSIUM PROCEEDS it will become increasingly apparent that the subject of plant composition in relation to those components of environment that affect growth and uptake of mineral elements presents many complexities and difficulties in interpretation. There are several reasons why this is so. Some arise from the characteristics of plants as living organisms. These can be charted if the investigator has sufficient patience and determination. Others arise from the interplay of climatic and edaphic factors. These probably cannot be brought fully under control in the precise type of experimentation that would be required to evaluate their relative importance. For example, one cannot carry out field experiments on the same soil in two different climatic areas, because the soil itself is a product of its environment. So one is left with a compromise type of experimental approach that only crudely controls the components of environment, and does not permit clear explanation of the responses found, or confident prediction of what is to be expected.

After considerable thought as to the type of presentation which might be most appropriate to the occasion, it seemed to me that it might be helpful to discuss in a broad way some characteristics of plants in relation to their composition and their environment without specific presentation of data, so that as the results of the farsighted, fundamental and detailed studies that have been carried out under the Nutrition Project at the Kellogg Farm are later reported, they can be reviewed against this general background.

PLANT CHARACTERISTICS

Of the various types of living organisms, the higher plants present problems of growth, morphology and composition that are considerably more complex than those encountered in animals or bacteria. Most of these relate in one way or another to the peculiar responsiveness of plants to the environment in which they develop. Plants are remarkably mutable or plastic organisms; they can survive and develop under conditions of light, temperature, water and nutrient supply that are greatly divergent from those that permit optimal growth. When subjected to such stresses, there may be considerable change in form. The appearance and habit of growth may be altered, or the sequence of physiological and morphological changes that marks the normal progress of a plant through flowering to maturity may be halted, delayed or accelerated. The transition between vegetative growth and reproductive activity is often a delicate one; a small change in the environment can determine whether the plant does or does not proceed from the vegetative to the reproductive stage. Plants have a unique capacity for regeneration after injury, a characteristic incidentally that the agronomist cruelly exploits in the management of forage crops. Plant tissues can withstand in a dormant condition environmental stresses that at other times would be most damaging.

All this amounts to the statement that in plants there can be great divergences from what might be considered the normal condition, divergences in size, shape, weight, appearance, and in the timing of the sequence of phases of its developmental physiology. Indeed, one cannot completely specify the normal without specifying

the environment in which it has developed. Divergences from the normal in plants can hardly be regarded as abnormalities.

PLANT COMPOSITION

To complete the setting of the stage we must consider next just what is implied by composition. This seems to depend somewhat on the context and background against which the subject is being considered. In some agricultural circles if one talks about the composition of a crop, it is the mineral constituents and nitrogen that are understood. This seems especially to be the case when the crop is consumed by livestock. In other nutritional circles, composition means primarily the content of certain vitamins, essential amino acids and growth substances that are of major concern in critical ration-building, yet which do not amount to more than a few percent of the whole. Rather less frequently, composition means all the major organic constitutents determined either empirically or accurately. Rarely does it mean in practice the total analysis of both inorganic and organic components.

In this symposium it is probable that the mineral constituents will receive much of our attention, but in discussing the question of environment in relation to the composition of plants, I would prefer to put myself in the last category listed above, and consider very generally both inorganic and organic components.

Furthermore, and greatly complicating the whole question of composition is the fact that the agricultural yield of crop plants is almost invariably that only of a part of the plant. It may be the mature grain, the immature root, the vegetative top growth, or the regrowth that occurs in forage crops following mowing or grazing. Rarely is it the case, even in the most academic of studies, that the whole plant is considered, although it is obvious that different plant parts are far from identical in composition with respect to organic components. Take for example the grain and the straw of a cereal—the grain is high in starch and relatively high in protein content, though the straw is low in both these components, but considerably higher in the structural cell wall constitutents, cellulose, hemicelluloses and lignin.

It is not perhaps so readily recognized that the inorganic constituents, and particularly those that are considered as the major nutrient elements can vary very widely in different parts of the same plant. In general, cereal grains and seeds have a greater approximation to constancy, or less divergence from the means due to environment, than do the vegetative parts of plants in this respect, even when mature. This is true of both inorganic and organic constituents. In immature and still actively growing tissues a much greater range in contents of mineral elements and nitrogen is encountered, and this is what makes the problem of forage crop composition so unpredictable.

UPTAKE OF INORGANIC IONS

To look more closely at the relationship between environment and content of mineral elements we must first ask ourselves whether growth and uptake of inorganic ions are directly related, growth being expressed as increase in dry matter. If they are, then any factor unfavorable to or repressing growth should also repress uptake; conversely, a deficiency in the supply of a nutrient element should cause a reduction in the amount of growth obtained.

That at least twelve elements must be available if normal plant growth is to be obtained is firmly established, but it is also recognized that some are quantitatively more important than others. Some such as nitrogen, phosphorus, and sulphur are directly involved as protein and nucleic acid constituents. The content of these elements in proteins and nucleic acids is fixed, and therefore protein synthesis and protein content is linked directly to the supply of all three.

At the other end of the line there are elements such as zinc, molybdenum, copper, and perhaps chlorine that appear to have catalytic roles in metal protein complexes. The requirements for these elements are not directly related to any major organic constituents.

In the middle position there are the monovalent and divalent cations, K, Na, Ca and Mg that have multiple roles, and which together maintain the cation/anion balance in the plant, and between which there is a considerable degree of interchangeability, but also some competitive effects. Though not required in proportion to any major organic constituent, the minimum requirement of these as a whole is clearly related to the amount of growth, but differs greatly between species.

It is abundantly established that the ion absorption process does not proceed without metabolic activity in the root tissues, and that energy has to be expended by the plant in ion accumulation. The energy system involved in almost all crop plants is aerobic, and the presence of insufficiency of oxygen, or too high a concentration of carbon dioxide, suppresses or inhibits nutrient uptake by most plant species. In terms of environment, therefore, either the waterlogging of soil, or too great compaction, is likely to be reflected in mineral composition, inasmuch as uptake of ions is suppressed whereas photosynthetic activities and dry matter increase are not immediately reduced proportionately. Moreover, in the zone of restricted aeration different ions are not equally affected. Potassium uptake seems particularly sensitive to oxygen deficiency in the root zone, and plants under such circumstances may have a significantly lower potassium content. Even differences in soil aeration due to the cultural practices followed may be reflected in the uptake of potassium on the heavier soils. In comparisons of effects of plowing with such tillage practices as disking, listing or subsurface tillage, numerous workers have shown either potassium deficiency symptoms or a lower po-

tassium content in the crop grown on the soils not plowed.

Apart from the requirement of expenditure of energy on the part of the plant in ion uptake, it is also recognized that ion absorption is an exchange process, and that ion accumulation is to a considerable degree selective. The initial exchange between the soil colloids and the root surfaces is not selective and not dependent on metabolism. The root surfaces reflect the ionic environment in which they develop. Active ion uptake, however, is characterized by partial selectivity, and dependence upon metabolism. The rate of ion uptake is not regulated by the needs of the plant, nor directly by the rate of growth of the plant expressed in terms of increase in dry weight. Moreover, the degree of selectivity is distinctly poor, and many elements such as sodium, silicon, or chlorine, not essential to plant growth, may be taken up in considerable amounts, energy having had to be expended to do so. The rate of uptake is perhaps more closely related to the supply than to the requirement. Quantities of essential elements greatly in excess of the requirement of the plant or its capacity to use them may be accumulated by the plant if present in the root environment. This is known as *luxury consumption* of a nutrient, about which more will be said later. Moreover, the degree of selectivity is so imperfect that an excess of an element, either essential or non-essential, may interfere or preclude adequate uptake of an essential ion, even though there is a sufficiency in the environment.

LUXURY CONSUMPTION

Taken together these features of ion uptake indicate a very imperfect procurement system. If applied in principle to a manufacturing process they would produce confusion, a welter of shortages, surpluses, bottlenecks and choked supply lines. Even the best production engineer could not deal with the situation, which he would regard as hopelessly inefficient. But this is not all bad because the plant has storage capabilities. Most elements, though not all, have considerable mobility, so that if the uptake at one period is greater than necessary to meet requirements, if, in other words, luxury consumption takes place, and if, later, the requirement rises, perhaps to a level well beyond the current uptake rate because the growth rate has increased, then the supply unused earlier can be drawn upon. This means then that the content of a particular element in a tissue may later decline through transport, either to another vegetative part, or with the onset of maturity, by transfer to the seed.

It is then this feature of luxury consumption of inorganic ions which introduces so many of the complexities into the study of the mineral composition of plants and plant parts, and accounts for the extraordinary range in content of certain nutrient ions that may be found in plants wholly normal in appearance.

Inherent in this concept of luxury consumption is a certain basal content of each nutrient element that completely provides for all growth requirements. This level has been called by Macy and others the *critical percentage* below which yield is adversely affected and above which luxury consumption takes place. (*See figure 1*). The critical percentage is not a fixed value for any plant. It changes with age and stage of development. It is influenced by the level of supply of other nutrients, and is in fact rather difficult to determine except in a negative way.

For maximum yields in any environment it would be desirable that the supply of each of the essential nutrients be such that at all times the critical percentage of each is maintained in the plant. This in practice would mean that there would have to be some degree of luxury consumption at all times, because there are no external indications of critical percentage. If this were done, then yields would be limited only by the influence of components of the environment other than nutrient supply on the growth of the plant. This is of course the agronomist's goal, but it must be admitted that it is not one frequently attained or easy to attain. If it were ordinarily attained then it would be comparatively easy to have under control the mineral composition of a crop. Any further addition of a nutrient would result in an increased content of that element, because one would be operating entirely within the zone of luxury consumption. Realistically, however, it must be admitted that most crops are grown in a zone of partial deficiency for one or several nutrients. This is probably especially the case with forage crops that find use as livestock feed.

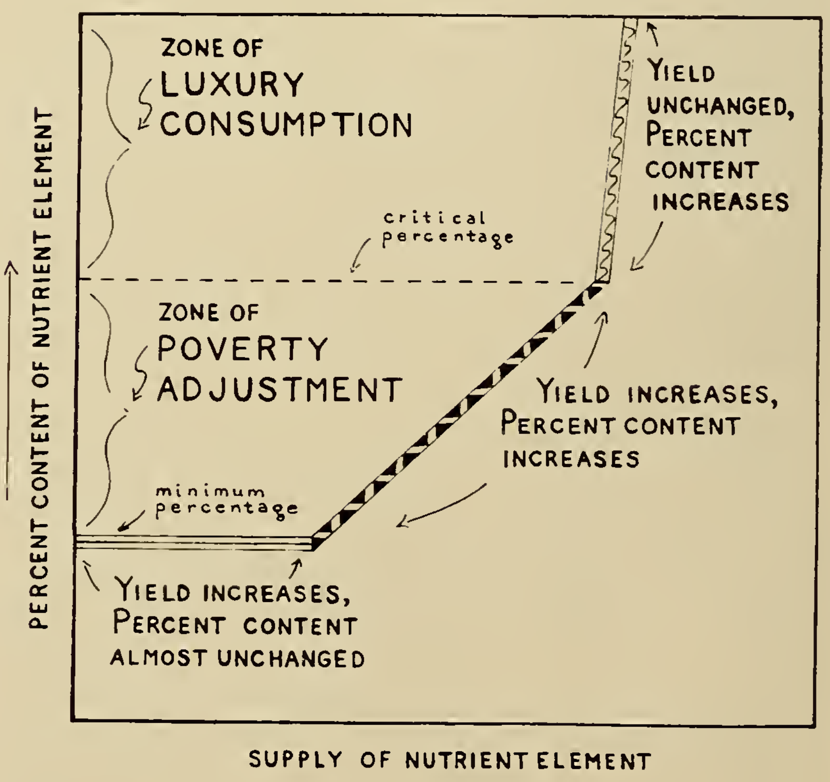

Fig. 1. Yield changes in the zone of poverty adjustment and in the zone of luxury consumption.

POVERTY ADJUSTMENT

In this condition of partial deficiency of one or more nutrients there is said to be *poverty adjustment* in content of the nutrient. The percentage content of the element in question will lie somewhere between the critical percentage, where the zone of adequacy is reached, and the minimum percentage which is the irreducible minimum content below which no plant is obtained. In this poverty adjustment zone there is an attempt on the part of the plant to adjust to the level of supply; it is indeed another example of the flexibility which the plant exhibits in its growth processes. In this zone an increase in supply of a deficient element will accomplish two things. It will produce an increment in yield, and it will bring about an increment in content. The percentage content of the element will be higher. The increase in content may be rather small, even though the yield increment is considerable, because the spread in percent content between the minimum percentage and the critical percentage is often not great. The critical percent is frequently less than twice the minimum percentage and sometimes considerably less.

CHANGES IN NUTRIENT SUPPLY

All this would be reasonably simple to follow and control if there were just one essential nutrient element, but it becomes extremely involved when there are many, and accounts for some of the seemingly paradoxical results in terms of plant composition that are obtained in some experiments in which the nutrient environment is changed by addition of fertilizers.

To give a simple example, if a pasture is severely nitrogen deficient so that growth is restricted and the yield low, the content of such elements as potassium, calcium and pehaps phosphorus may be high. At that level of nitrogen supply the herbage may be in a state of luxury consumption for potassium, calcium and phosphorus. If nitrogen is added growth is no longer limited, a higher yield is obtained and the percent content of potassium, calcium and phosphorus will fall, perhaps into the zone of poverty adjustment for one or more of them unless they are in unusually ample supply. Because the phosphorus requirements are tied to nitrogen in protein synthesis, increasing increments of nitrogen call for proportionate increments of phosphorus. If the phosphorus supply is limited the phosphorus content may fall to its minimum percentage, and phosphorus would then be severely limiting yield. The nitrogen supply might then put the plant into the zone of luxury consumption with respect to nitrogen, with the appearance of nitrates or amides in the tissues.

High yields are not therefore synonymous with a high content of nutrient elements; crops from well fertilized plots may have a lower content of some essential elements than those from poorly yielding plots, the addition of a fertilizer may cause a reduction in content of some of the other nutrient elements, or, if the supply of several of the major elements is such that the content of each in the plant falls in the poverty adjustment zone, moderate addition of one of them may have rather little effect on content. We may see examples of each of these situations later in the experimental data to be presented.

PLANT GROWTH AND CROP YIELDS

The agronomist and the farmer are ordinarily preoccupied with yield. They are rarely concerned with mineral composition. The varieties selected, the cultural practices followed, the fertilizers applied, all are decided on the basis of yield expectation. It is generally assumed that yields in the field are mainly limited by sub-optimal environmental conditions of nutrient supply and water supply. These are factors which are susceptible of some control. The broader climatic and edaphic factors that cannot be controlled are taken into account in the selection of an adapted variety. The agronomist attempts to employ in each environment crop plants possessing characters that make them best adapted to that environment, when measured in terms of yield and certainty of yield. This is done empirically with little or no information as to how one or any of these components of environment may affect growth and yield. Even the climatic extremes, such as high temperature or early frost, that can introduce uncertainty in yield expectations, may be one of the considerations in selection of an adapted variety.

Crop improvement through crop breeding has been spectacularly successful. This has been accomplished by application of the most refined genetical techniques, but in other respects progress has been essentially empirical because the inherent characteristics of the germ-plasm employed have usually been poorly understood or poorly defined. The breeder does not understand or understands only imperfectly why one variety outyields another in the same environment, or why the seed of one variety has a higher protein content than that of another on the same soil. The real problems of yield and composition and varietal differences lie in the physiological mechanisms of the plant, in its photosynthetic efficiency and biosynthetic abilities, and in the impact of environment, including the nutrient supply, on these.

The growth activities of the plant involve many processes not all influenced equally by external factors. Some of these can be studied in elaborate controlled-environment chambers. Simple factors such as light or temperature, or more complex factors such as day length or thermoperiodicity, can well be approached on such a basis. But alone these do not provide the answers to all the relationships between the crop and its environment. There must be consideration given to population interactions. The plant must be grown under field conditions with the normal spacings, cultivations, etc., or if a sward then it must be subjected to

mowing or clipping. We must remember too that under natural conditions it is rare for both ends of a plant to be at the same temperature. The tops may be warmer, often much warmer than the roots during the day, and cooler at night. All parts of the root system are not exposed to the same nutrient environment, indeed some placement practices involving hill application or banding of fertilizers deliberately accentuate the differences in nutrient environment between one part of the root system and the remainder. All parts of the root system are not supplied with water at equal availability. The deeper roots may be in moist soil and the shallow roots in drier soil, or vice versa. Controlled environment experiments, though they may help in the understanding of the problem, simplify the situation too much when it comes to the field behavior of a crop.

GROWTH ANALYSIS AND PLANT COMPOSITION

The role of environmental factors can be studied in relation to total dry weight or to dry weight changes in plant parts. Growth in size and weight primarily involves the photosynthetic efficiency of the plant. This is the dry matter gain in the leaves through photosynthesis less the loss due to respiration in all plant parts, and can be expressed in terms of efficiency per unit leaf area. This is sometimes called the *net assimilation rate*. The rate of accumulation of dry matter, or the rate of growth is then given by multiplying the net assimilation rate by the total leaf area. Studies on the net assimilation rate of crop plants have led to the conclusion that, although not a constant, it is not particularly responsive to changes in environment. It does change a little with age and species, but the really significent differences are encountered in the other component of yield, namely leaf area, and in the duration of preservation of maximum leaf area per crop acre. There are indications that in some crops the attainment of maximum leaf area and maximum net assimilation rate do not coincide. In others the duration of retention of leaves with high net assimilation rate is short. The nutritional status and the moisture regime appear to have a greater influence on total leaf area and leaf duration than on the net assimilation rate, and it may well be that yield increments due to applications of fertilizers, and particularly to nitrogenous fertilizers, are the resultant of changes which they bring about in leaf area and leaf area maintenance.

In the vegetative phase of development increase in dry weight has been compared to a process of continuous compound interest, the interest or increment produced in any interval being added in the form of leaves to the capital for growth in subsequent periods. This is true only when on the lower part of the sigmoid curve that represents all the growth changes from seedling to maturity. The product of net assimilation rate and leaf area determines the rate of increase in weight, but the nature of the compounds synthesized and the proportions in which they are laid down depend on the developmental stage, which can be greatly affected by the environmental conditions. Day length, temperature flux, night temperature, moisture supply, each may influence the transition from vegetative phase to reproductive phase. This is the step which brings about the substantial changes in composition. There will be little or no increase in the number of leaves, daily weight increments diminish, secondary thickening of cell walls in the stems proceeds apace, the lignin content of such tissues rises, starch may accumulate in the seed, starch or other carbohydrate reserves may be deposited in the roots or rhizomes, leaves may be depleted of nitrogen, and uptake of mineral nutrients by the roots diminishes and eventually ceases. These are the great changes that affect and determine the organic composition of the plant. Varietal differences are essentially minor in comparison to the major changes accompanying maturation. One needs therefore to examine any problems involving the influence of environmental factors on plant composition with two considerations in mind, first, what effect there may be on the growth rate, and second, what effect there may be on the development sequence on ontogeny of the plant.

CONCLUSIONS

One ought to conclude a review of this type by developing some generalized conclusions that express the relationship between plant composition and environment in a simple way, capable of being applied to the many different kinds of problems that arise in the utilization of plants or plant parts for food or as industrial raw materials. Unhappily, this cannot be done. One can at present perhaps do rather better with respect to the mineral constituents than the organic constituents, but even with mineral constituents the information tends to be more descriptive than explanatory. It might run as follows:

1. Although uptake of mineral elements involves the expenditure of energy by the plant, the rate and amounts absorbed are not proportional to the rates and amount of dry matter increase, and are not equally influenced by the same components of the environment.

2. Uptake of nutrient elements is not limited to the requirement either for minimum or optimal growth.

3. Any environmental factor that represses growth may result in an increase in content of mineral elements, unless root function is directly interfered with.

4. Luxury consumption of mineral elements occurs when they are in good supply.

5. Increasing the available supply of a nutrient element will not proportionately increase the content of that element in the plant unless the supply initially was adequate.

6. Increasing the available supply of a nutrient element that is deficient can result in a lowering of the content of other mineral elements.

7. Growth, as measured in dry weight increase, is dependent on the efficiency of the leaves and the total leaf area. The latter is far more responsive than the former to environmental changes.

8. Composition, in terms of the organic constituents, is greatly influenced by the stage of development of the plant, and notably by the transition from the vegetative to the reproduction condition, and the onset of maturity. This transition may be controlled by factors in the environment which do not necessarily affect growth rate, though adverse growth conditions may also accelerate this change.

9. Most of the factors affecting the content of inorganic and organic constituents in crop plants and plant parts are not easily controlled, particularly if maximum yields are also required.

Effects of Fertilizer Practices On Plant Composition

I FIELD RESULTS[1,2]

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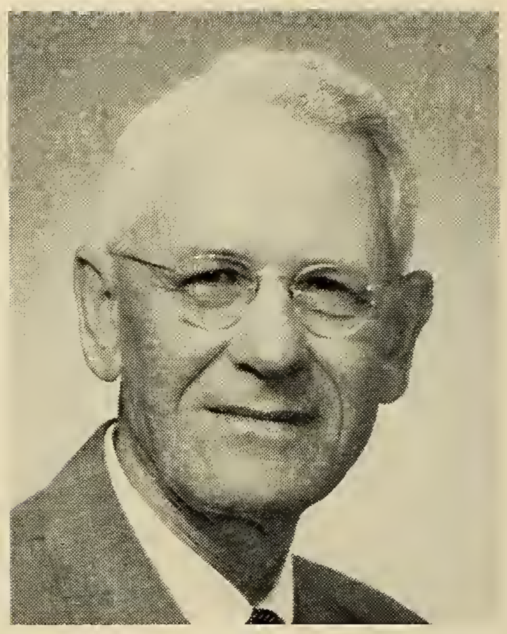

PROFESSOR C. W. DUNCAN of the Department of Agricultural Chemistry at Michigan State College. Mr. Duncan, a member of the staff at MSC since 1929, is the author of more than 90 articles, pamphlets, and books in the field of dairy science.

THE EFFECT OF FERTILIZERS on the chemical composition and feeding value of plants has been a subject of interest to a large group of people for some time. It has been found that wide variations occur in the mineral content of the same plant species grown in different parts of the country. Various authorities have proposed logical interpretations for these differences, but some of these interpretations appear to be contradictory. Actually, most of the controversy arises from the interpretation of experimental results obtained under certain specified conditions and then in attempting to apply broad generalizations to these findings.

It has been established that seasonal variations in growth and in chemical composition are conditioned to a large extent by climatic factors, such as temperature, humidity, rainfall and sunshine, and also by soil moisture and fertilizer treatment, but the literature pertaining to the effects of soil, fertilizers, and climatic conditions cannot be reviewed at this time. Dr. Norman has just presented a very informative discussion on the influence of environmental factors on plant composition; other discussions of a related nature will follow in the symposium.

The problem at hand is concerned primarily with the chemical composition of the same plant species grown on (1) fertilized and (2) badly depleted soil of the same type. The plants had been harvested for cattle feed. The same environmental factors influenced the growth and chemical composition of the plants grown on the experimental farm, since both crops were grown on approximately adjacent plots. The only difference between the crops was in the application of fertilizer to some of the plots. The objectives of this portion of the project were to determine whether differences occurred, first, in the chemical composition of the same plant species grown on fertilized and unfertilized soil, and second, in the nutritive value of these feeds when consumed by dairy cattle. Since the use of fertilizers to increase yields has been established many times, the objectives did not include a determination of differences in total yields.

EXPERIMENTAL

Corn and soybeans were raised in rotation on the farm every year. Wheat and oats were also raised during some of the years. Oat hay, brome grass hay, and timothy hay were raised at intervals during the experiment and either one or the other constituted the roughage portion of the ration for the cows. All of the crops were harvested at the proper stage of maturity by the usual farm machinery, transported to a college barn for storage, and then fed to the cattle during the year as their sole ration. The data presented in this paper, therefore, are representative of the composition of the feeds as fed to the cattle.

Care was exercised in obtaining representative samples of these feeds for chemical analysis. The samples were obtained about three times a year, usually in November, February and April, and were analyzed for moisture, ash, calcium, phosphorus, magnesium, potassium, iron, copper, cobalt, manganese, crude fiber, total nitrogen, ether extractives, fermentable carbohydrates, and carotene by the methods recommended by the Association of Official Agricultural Chemists (1).

[1]Supported in part by a grant from the National Dairy Council on behalf of the American Dairy Association.
[2]The Nutrition Committee takes this opportunity to thank Dr. E. J. Benne of the Department of Agricultural Chemistry and his staff for making all of the chemical determinations on the feed and soil samples involved in this project.

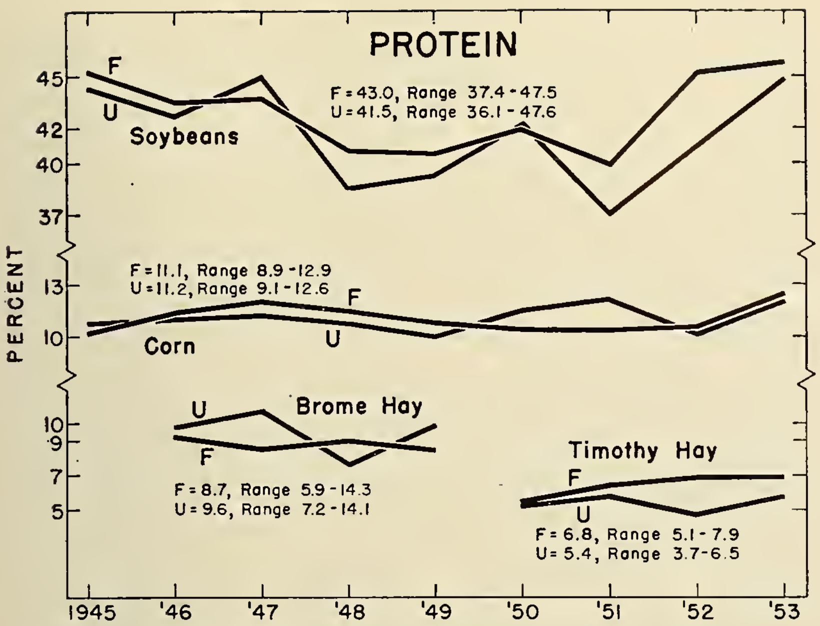

Fig. 1. The variations obtained in the protein content of soybeans, corn, brome and timothy hay from year to year.

RESULTS AND DISCUSSION

The results that were obtained are shown in *figures 1 to 10,* inclusive and in *tables 1 to 2. Figure 1* shows the protein content of the soybeans, corn, brome, and timothy hay. All of the data are expressed on the moisture-free basis and show the average value obtained each year that the crop was grown. The letter F indicates that the crop was grown on the fertilized soil and U represents that grown on the unfertilized soil.

The data indicate that rather large differences occurred in the protein content of soybeans from year to year. These variations are obtained for the soybeans grown on both the fertilized and unfertilized soil. In 1947 and 1950, the protein content of the unfertilized soybeans was higher than that found in the soybeans grown on the fertilized soil. The variations due to climatic conditions from year to year were frequently greater in both the fertilized and unfertilized soybeans than the variations due to fertilization. The large differences noted in protein content for the years 1948, 1951 and 1952 may have been due to fertilization. The average value obtained for all of the soybeans grown on the fertilized soil was 43.0 percent compared to 41.5 percent for those grown on the unfertilized soil.

The protein content of the corn shows essentially the same picture as that obtained for soybeans in respect to the differences due to climatic conditions. The average protein content of the corn grown on the unfertilized soil was just as high as that found for the corn grown on fertilized soil. These results confirm those of Weeks and Fergus (4), Harshbarger *et al.,* (2), and others. The seasonal differences in the protein content of the corn were less marked than that found for the soybeans.

The protein content of the brome hay grown on the unfertilized soil was higher in 3 of the 4 years than that found in the hay grown on the fertilized soil. This may have been due to the stage of maturity at the time the hays were harvested. The seasonal changes in the protein content of the unfertilized brome were more marked than those found in the fertilized hay.

Timothy hay responded differently than the other three crops to fertilization. The average protein content was consistently higher in the hay grown on the fertilized soil (av. 6.8 percent) than in that grown on the unfertilized soil (av. 5.4 percent). This is the only case in which the application of a complete fertilizer definitely increased the protein content of the crops grown on the experimental farm. The data indicate that all of these crops showed strong seasonal variations in protein content. The crops grown on the unfertilized soil showed greater variation than the crops grown on the fertilized soil. Timothy showed the greatest response to fertilization, whereas corn and soybeans showed the least.

Figure 2 shows the calcium content of the same crops. These data indicate that very little difference was found in the calcium content of soybeans, corn or brome that could be attributed to fertilization. The unfertilized crops contained as much or more calcium as the crops grown on the fertilized soil. Three tons of lime per acre had been added to the fertilized soil on two occasions, but this was not reflected in the calcium content of the crops. Here again, climatic conditions produced more changes in calcium content of these three crops than was produced by fertilization. The seasonal effects were particularly noticeable in the calcium content of soybeans grown in 1946, 1947 and 1951, and for corn grown in 1945, 1949 and 1953. The application of lime and fertilizers to the soil seemed to exert a negligible influence on the soybeans, corn and brome

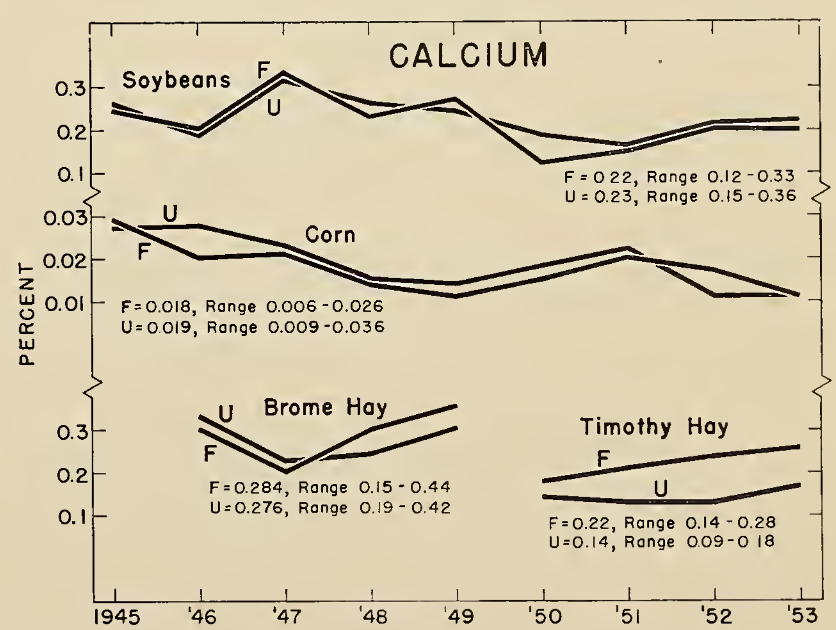

Fig. 2. The variations obtained in the calcium content of soybeans, corn, brome and timothy hay from year to year.

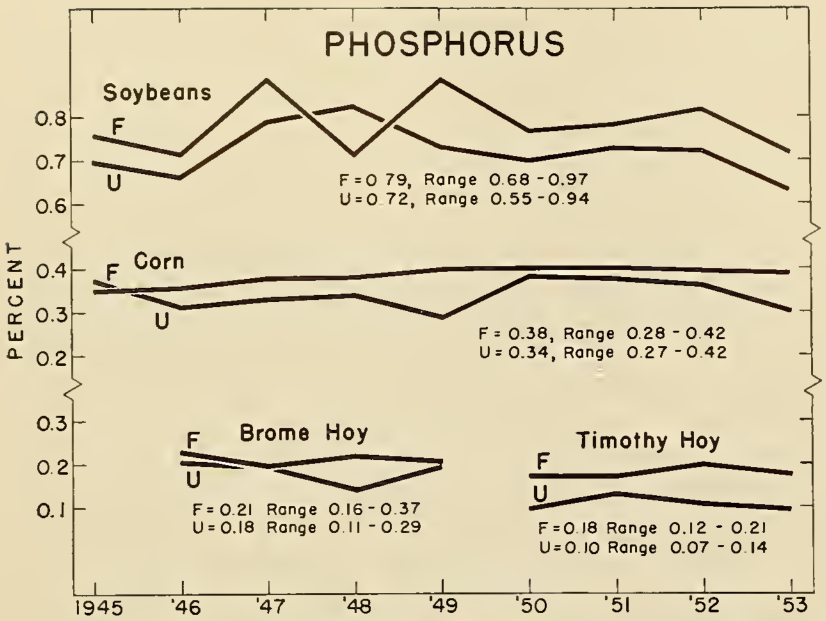

Fig. 3. The variations obtained in the phosphorus content of soybeans, corn, brome and timothy hay from year to year.

hay. Timothy, however, responded differently; the calcium content of the timothy hay grown on the fertilized soil was markedly higher than that grown on the unfertilized soil.

The average phosphorus values obtained for the soybeans, corn, brome and timothy hay for each year that they were grown are presented in *figure 3*. The soybeans grown on the fertilized soil contained slightly more phosphorus, on the average, than the soybeans grown on the unfertilized soil, but large seasonal differences are noted in both crops. The corn grown on the fertilized soil contained slightly more phosphorus than the corn grown on the unfertilized soil, but in this case, the seasonal differences were not as pronounced in the fertilized corn as in the unfertilized corn. The fertilized brome hay contained slightly more phosphorus than the unfertilized hay.

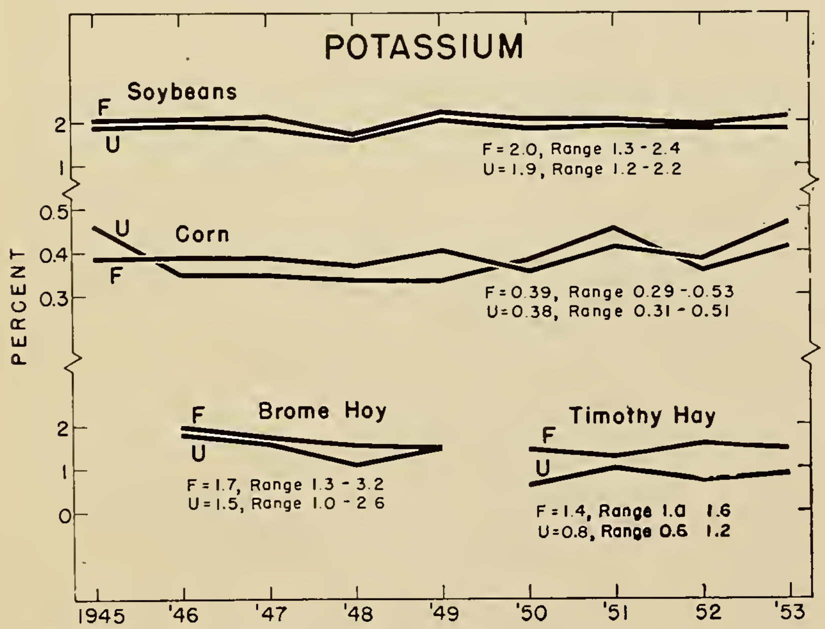

Fig. 4. The variations obtained in the potassium content of soybeans, corn, brome and timothy hay from year to year.

The data indicate that the effect of fertilization was pronounced so far as the timothy hay is concerned. Almost twice as much phosphorus was present in the fertilized hay as was found in the unfertilized hay. The feeding characteristics of different plant species appear to influence their ability to take phosphorus from the soil. This is indicated by the large difference in the phosphorus content of unfertilized timothy as compared to the other crops grown on the unfertilized areas.

Figure 4 shows the average yearly variation ,in the potassium content of the four crops. The potassium values obtained for the soybeans, corn and brome hay grown on both the fertilized and unfertilized soil do not indicate any differences that can be attributed to fertilization, but a marked difference is noted between the potassium content of the fertilized and unfertilized timothy hay. The yearly variations in climatic condi-

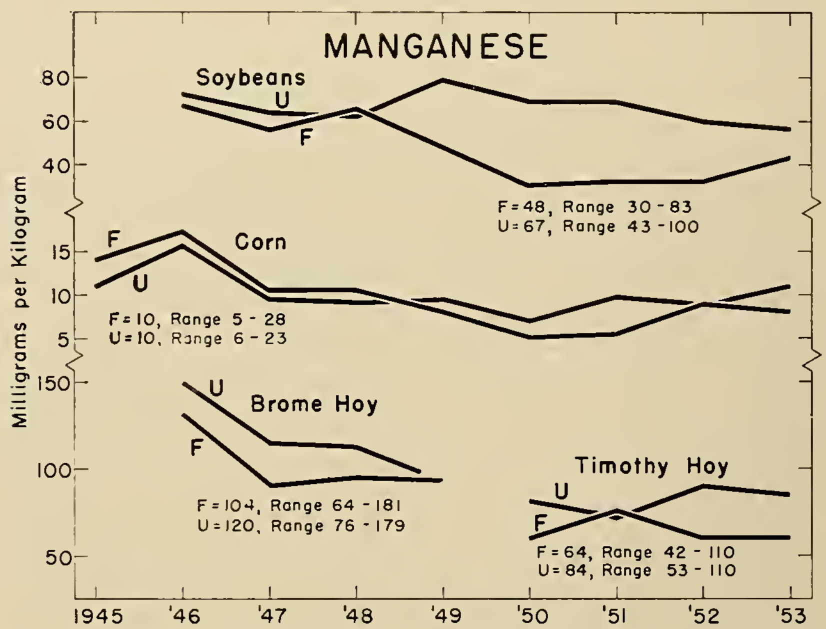

Fig. 5. The variations obtained in the manganese content of soybeans, corn, brome and timothy hay from year to year.

tions appear to have had less influence on the potassium content of the crops than was observed for either the protein or phosphorus contents.

The average manganese values obtained for the various crops grown on the experimental farm are shown in *figure 5*. It should be recalled that the fertilized soil had 6 tons of lime applied per acre; consequently, the pH of the fertilized soil was higher than the unfertilized soil. The difference is reflected in the large differences in the manganese content of the soybeans grown after 1948. The more acid soil tended to increase the manganese uptake and the less acid soil tended to decrease the manganese uptake in the soybeans. The pH of the soil appeared to have had little influence on the manganese content of corn. The average values were the same (10 mg. per kg.) whether the corn was grown on fertilized or unfertilized soil. Season had more influence on the manganese

content of corn than either lime or fertilization. Slightly more manganese was found in the brome hay grown on the unfertilized soil; however, the range of values for both hays were the same. The influence of lime was evident in the manganese content of timothy hay, although season appears to have as much or more influence on the manganese content of the other crops as the pH of the soil.

From the data presented in *figures 1 to 5,* inclusive, it is apparent that the climatic conditions exerted more influence on the protein, calcium, phosphorus, and manganese content of the soybeans, corn and brome hay than the presence or absence of fertilizers. Fertilization favorably influenced the nutrient content of timothy, but large seasonal variations also were in evidence.

Figures 6 to 11, inclusive, show the average composition of the feeds grown on both the fertilized and unfertilized soils in more detail. The average values obtained for the various nutrients in soybeans for the 9-year period are shown in *figure 6.* The letter F represents the crop grown on the fertilized soil and U represents the crop grown on the unfertilized soil. The letter M represents the average value listed in appendix *table 1* in Morrison's (3) book on "Feeds and Feeding." This table is a compilation of all the available data on the composition of American feeding stuffs that have been published in bulletins and reports from the State Experiment Stations, the United States Department of Agriculture, the National Research Council, and various scientific journals. It represents, therefore, the most comprehensive and accurate data available for comparative purposes and has been included in this and the following graphs to show whether the various constituents in the feeds grown on the fertilized and unfertilized soils were above or below the average values compiled by Morrison. The major constituents are expressed on the percentage basis and the minor elements are expressed in milligrams per kilogram. All values are expressed on the moisture-free basis.

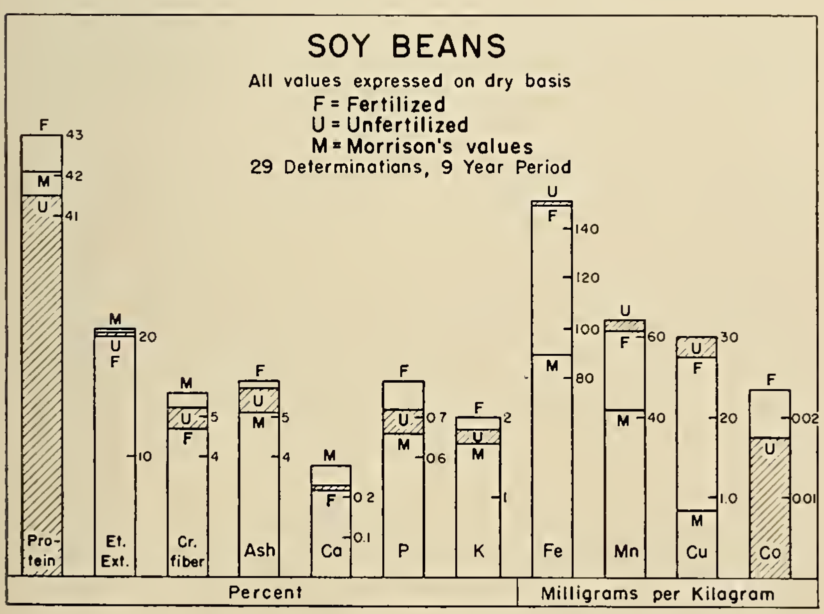

Fig. 6. A comparison of the average values obtained for soybeans grown on fertilized and unfertilized soil with those compiled by Morrison (3).

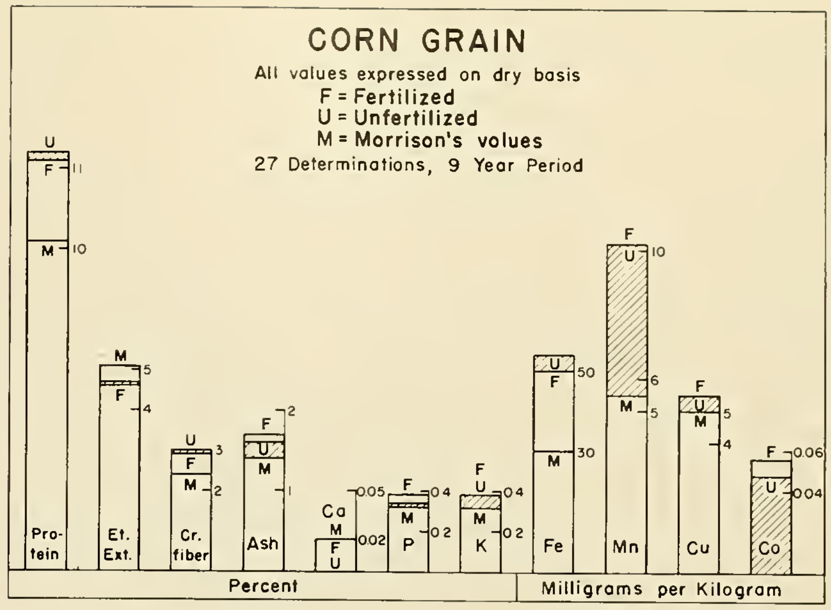

Fig. 7. A comparison of the average values obtained for corn grown on fertilized and unfertilized soil with those compiled by Morrison (3).

Morrison's value for protein was found to be intermediate between that obtained for the soybeans grown on the fertilized and unfertilized soil. The soybeans grown on both the fertilized and unfertilized soil were higher in ash, phosphorus and potassium, and slightly lower in crude fiber and calcium; the iron, manganese and copper values were about twice as high as Morrison reported. Little difference, however, was found between the concentration of the various minor elements in the soybeans grown on either the fertilized or unfertilized soil.

Figure 7 shows the 9-year average values obtained for the shelled corn grown on the fertilized and unfertilized soils and Morrison's average values for U. S. No. 3 corn (values for U. S. No. 2 are approximately the same). It is of interest to note that the protein, crude fiber, ash, phosphorus and potassium content of both the fertilized and unfertilized corn are higher than those reported by Morrison. The calcium content was the same, but the amount of ether extractives was slightly less. About twice as much iron and manganese were found in the corn grown on both the fertilized and unfertilized soil as Morrison reported, but the copper content was about the same. Under the conditions of this experiment, the pH of the soil appeared to have little influence on the manganese content of shelled corn. In general, the fertility of the soil apparently exerted little influence on the nutrient content of corn.

The average values obtained for the wheat grown on the farm for 4 years are presented in *figure 8.* The protein content of the wheat grown on the unfertilized soil was higher than that grown on the fertilized soil, and both crops contained less protein than the average value reported by Morrison. The other major constituents showed remarkable agreement among them-

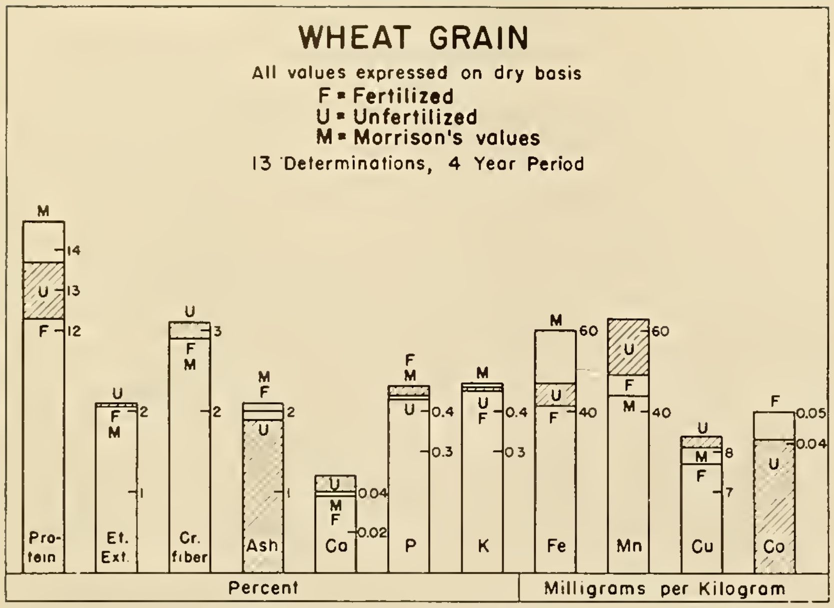

Fig. 8. A comparison of the average values obtained for wheat grown on fertilized and unfertilized soil with those compiled by Morrison.

selves as well as with Morrison's values. Morrison's average value for the iron content of corn is higher than was found in the corn grown on either the fertilized or unfertilized soil, but the reverse was found for manganese. In so far as these nutrients are concerned, no difference was found in the composition of wheat that could be attributed to the use of fertilizers.

Figure 9 shows the 6-year average values obtained for the oats grown on the fertilized and unfertilized soil and Morrison's average values. The data show that no difference was found in the protein content of oats grown on the fertilized or unfertilized soil, but both of the experimental values were higher than the average value reported by Morrison. The other major constituents, with the exception of ash, agree very closely among themselves as well as with those reported by Morrison. The ash values, however, are about 25 per-

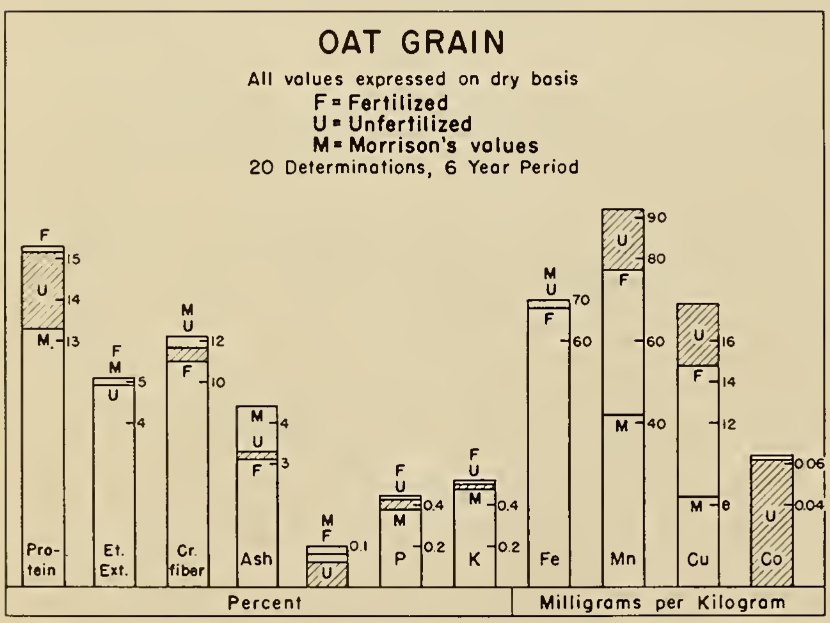

Fig. 9. A comparison of the average values obtained for oats grown on fertilized and unfertilized soil with those compiled by Morrison (3).

cent lower than Morrison reported. The iron values are comparable, but twice as much manganese and copper were found in the experimental crops as Morrison reported. The more acid soil apparently was favorable to an increased uptake of manganese and copper. Under the conditions of this experiment, the application of lime and fertilizers did not favorably influence the nutrient content of oats.

The 4-year average values obtained for brome hay grown on the fertilized and unfertilized soils are shown in *figure 10*. The data indicate that the hay grown on the unfertilized soil contained as much or more protein, fat, and calcium, but slightly less crude fiber, phosphorus, and potassium as the hay grown on the fertilized soil. The ash content of the unfertilized hay was markedly less than that found in the fertilized hay. All of the experimental values, with the exception of crude fiber and calcium, are lower than the average values reported by Morrison. The values obtained for iron, manganese, copper and cobalt show good agreement among themselves, but the experimental copper values are more than twice as high as Morrison's value. The

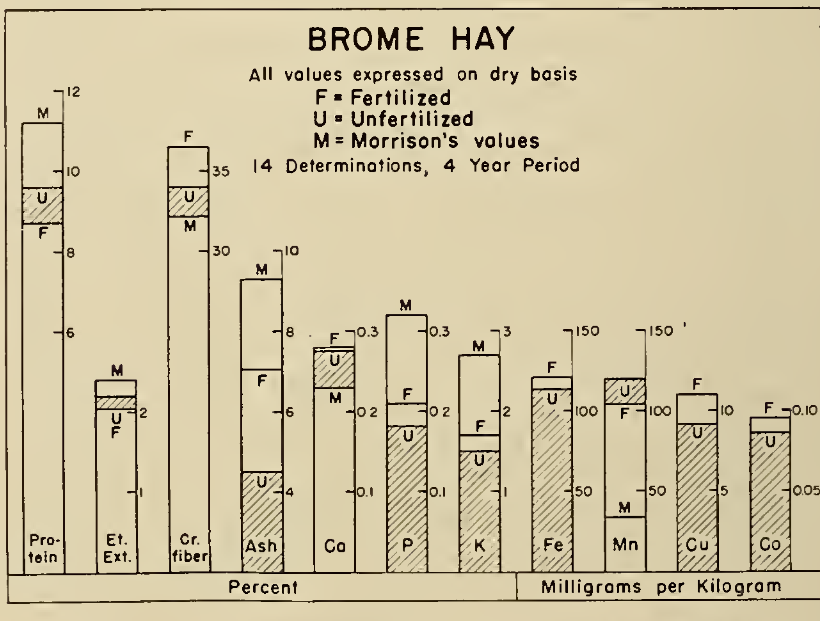

Fig. 10. A comparison of the average values obtained for brome grass hay grown on fertilized and unfertilized soil with those compiled by Morrison (3).

differences observed in the protein, crude fiber, and ash content of the fertilized and unfertilized brome hay conceivably may be accounted for by the difference in the stage of maturity of the two hays at the time they were harvested. The unfertilized hay was short and leafy whereas the fertilized hay was tall and course; therefore, it is difficult to draw valid conclusions concerning the effect of fertilizers on the chemical composition of brome hay. The data indicate, however, that the nutrient content of the two hays was approximately equal, except for ash content, at the time they were fed to the cows.

Figure 11 shows the 4-year average composition of the timothy hay that was grown on the fertilized and unfertilized soil. Timothy is the only plant species

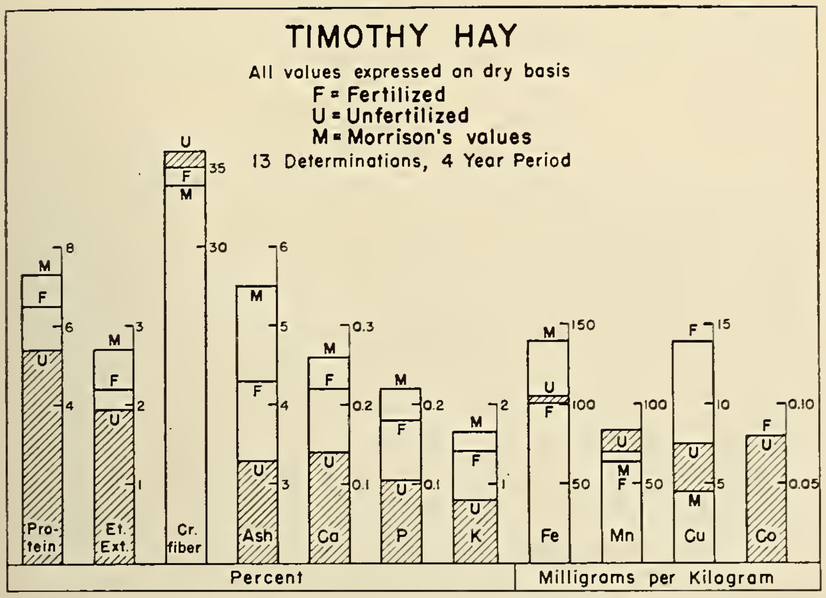

Fig. 11. A comparison of the average values obtained for timothy hay grown on fertilized and unfertilized soil with those compiled by Morrison (3).

grown on the farm that has consistently shown a difference in composition that can be attributed directly to fertilization. All of the major nutrients in the fertilized timothy hay, except crude fiber, were higher than was found in the unfertilized hay. This is particularly noticeable in the ash, calcium, phosphorus and potassium content of the fertilized hay. The data show that none of the values obtained for the major nutrients are as high as Morrison reported. So far as the minor elements are concerned, the hays grown on the fertilized and unfertilized soils were approximately equal in concentration, except for the copper content of the unfertilized hay. The copper content of the fertilized hay was about twice as high as that found in the unfertilized hay. Morrison reported a higher iron value, a lower value for copper, but the same value for manganese. The timothy plants grown on the unfertilized soil illustrate a difference in the ability of different plant species to absorb nutrients from badly depleted soil. None of the other plant species that were harvested at the proper stage of maturity for animal feeding purposes have shown any marked difference in chemical composition that can be attributed to fertilization.

Brome grass was cut at three different vegetative stages to determine whether a difference could be found in the chemical composition of this plant species that might be related to fertilization or lack of fertilization. The results are presented in *table 1*. The organic constituents in both the fertilized and unfertilized grasses were approximately equal each time the samples were taken. Crude fiber advanced markedly with the stage of maturity, whereas the protein and carotene content decreased. The effect of fertilization was not evident so far as these constituents were concerned. All of the inorganic constituents decreased progressively as the plants became more mature and slight differences were evident in favor of fertilization. These results are in agreement with those shown in *figure 10* for the average composition of brome hay.

Table 2 shows the composition of fertilized and unfertilized corn stalks and corn cobs. These samples were taken about 2 weeks before the corn was cut for silage when the fields were randomized to estimate the amount of shelled corn that would be in each silage. The fertilized corn had begun to dent while the unfertilized corn was still in the dough stage. The difference in maturity is illustrated by the higher crude fiber and lower protein and mineral content of the fertilized corn. The unfertilized corn stalks contained less fiber and more protein and minerals. The data show that about twice as much manganese and iron were present in unfertilized stalks as was found in the fertilized stalks, although the shelled corn was shown to contain the same amounts of iron and manganese regardless of whether it was grown on fertilized or unfertilized soil (*figure 7*). The data show essentially the same picture for the corn cobs. The higher mineral content of the unfertilized stalks and cobs was probably due to a slower rate of maturity.

SUMMARY

The chemical composition of the same plant species grown on fertilized and unfertilized soil of the same type has been determined. The data indicate that the relatively small differences that occurred in the composition of the soybeans, corn, wheat, oats and brome hay in any one year could not be attributed to fertiliza-

TABLE 1—Influence of soil fertility on the composition of brome grass cut at three stages of maturity (All values expressed on the dry basis)

		Samples cut			Samples cut		
		5/18	6/5	6/19	5/18	6/5	6/19
		Fertilized			Unfertilized		
Crude fiber	%	23.1	30.1	32.7	21.9	28.0	35.2
Protein	%	20.0	10.6	8.2	21.1	11.0	8.9
Carotene	γ/g	252	138	101	258	155	93
Ash	%	8.8	6.3	5.4	7.6	5.2	4.4
Potassium	%	2.8	2.3	1.8	2.0	1.6	1.4
Phosphorus	%	0.43	0.31	0.26	0.34	0.24	0.19
Manganese	γ/g	103	73	70	117	91	95

TABLE 2—Influence of soil fertility on the composition of the vegetative portion of plants (All values expressed on the dry basis)

		Corn stalks		Corn cobs		Soybean stems and pods	
		F.	U.	F.	U.	F.	U.
Crude fiber	%	36.0	33.4	35.0	34.0	46.5	46.9
Protein	%	5.4	5.9	2.6	2.8	4.6	3.6
Ash	%	4.8	6.1	1.6	2.2	6.9	7.8
Calcium	%	0.54	0.44	0.02	0.03	0.79	0.75
Phosphorus	%	0.12	0.07	0.04	0.04	0.10	0.05
Potassium	%	0.77	0.80	0.60	0.81	1.18	0.21
Manganese	γ/g	80	165	10	17	53	102
Iron	γ/g	213	316	61	51	472	790

tion. The composition of timothy hay was favorably influenced by fertilization. The climatic conditions that prevailed during each growing season caused a greater variation in the chemical composition of these crops than the presence or absence of fertilizers.

The lack of difference in the chemical composition of mature cereal grains grown on fertilized and unfertilized soil probably lies in the fact that the primary function of these seeds is for the propagation of the plant species rather than to supply feeding stuffs. If a soil contains a sufficient quantity of all of the essential minerals in an available form for the growth of plants, the seeds apparently have a normal composition.

The application of a complete fertilizer permits more plants to grow in a given area, each plant can produce more seeds, but the composition of the seeds is not affected appreciably by fertilization in the amounts ordinarily applied in good agricultural practices.

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Effects of Fertilizer Practices On Plant Composition

GREENHOUSE RESULTS

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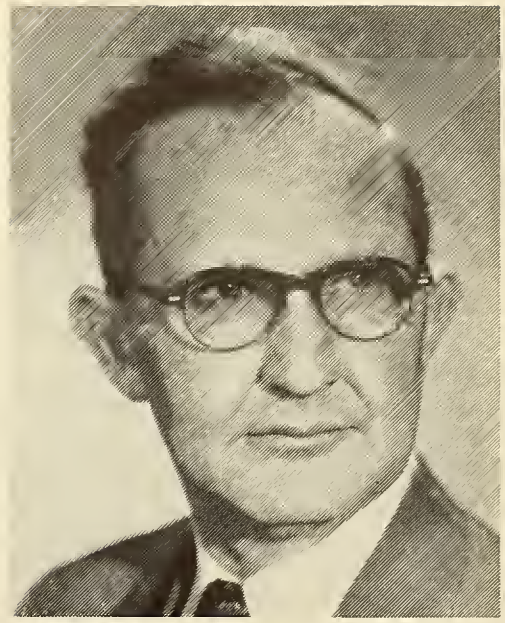

DR. R. L. COOK, Head of Soil Science Department at Michigan State College. Since Dr. Cook first joined the staff in 1927 he has been the author of approximately one hundred papers for professional journals and various publications.

THE EFFECT OF SOIL FERTILITY upon the nutritional value of foods and feed has been, for a number of years, the subject of much discussion among those interested in human and animal nutrition. The subject has caused the initiation of a large number of studies by many experiment stations. One such project was initiated by the Michigan Agricultural Experiment Station (3)[1]. In this work, part of a depleted Michigan farm was limed and fertilized while the remainder of the farm was left in a depleted condition. The crops grown on these two areas were fed to two comparable herds of dairy cattle. Milk production, composition of the milk, health and reproductivity of the cattle, and the nutritive value of the milk were studied.

Chemical analyses revealed only minor differences in the composition[2] of the plants produced on the fertilized and unfertilized areas of the farm. According to the concept of plant nutrition proposed by Shear, Crane, and Myers (6), this result may have occurred because liming and fertilizing only increased the intensity of nutrient supply, but had no effect upon the balance of nutrients in the soil. Thus, only increased plant growth resulted with very little change in plant composition or nutritive value. Therefore, a greenhouse experiment was initiated to study the effects of both unbalanced fertility conditions and different intensities of nutrient supply upon plant composition. The results are presented in this paper.

The chemical composition of plants is determined by many factors other than the level of soil fertility. They include soil moisture, light intensity and duration, temperature, species and variety of plant, plant organ or tissue analyzed, and stage of maturity. Divided into two broad categories, the factors are genetic or environmental. The influence of the genetic factors has been studied for a number of years, but only recently the importance of the environmental factors has been recognized. It frequently appears that some of these environmental factors, such as soil type or climate, may exert a greater influence on plant composition than does the fertility status of the soil (7). For instance, Beeson reported (1) that unfertilized forage in Michigan generally has a higher phosphorus content than does heavily fertilized forage in Alabama. Thus, it may be seen that the frequent contradictions reported in the literature concerning the effects of a certain soil treatment upon plant composition may be explained by differences in the combinations and levels of these environmental factors.

METHOD OF STUDY

One-gallon greenhouse pots were filled with Fox sandy loam soil taken from the depleted area of the nutrition farm. The original pH of the soil was 4.7. Three additional soil pH values, 5.8, 6.3, and 6.8 were obtained by making applications of calcium carbonate or a mixture on a weight basis of 75 percent calcium carbonate and 25 percent magnesium carbonate. Available soil phosphorus was adjusted to levels of 30, 60 and 90 pounds per acre (as measured by the Spurway reserve method) by the addition of monocalcium phosphate as fertilizer. Potassium chloride was added at three rates to give levels of 100, 200, and 300 pounds of available potassium per acre. The seven lime treatments, three phosphorus, and three potassium treatments were combined in a complete factorial design, giving 63 different soil treatments. In addition, a

[1]Supported in part by a grant from the National Dairy Council on behalf of the American Dairy Association.
[2]Unpublished data.

control for each lime treatment was included, to which no phosphorus or potassium fertilizers were added. Such soil gave tests for available phosphorus and potassium of 13 and 60 pounds per acre respectively. Thus there was a total of 70 soil treatments, each replicated four times. Other nutrients were supplied to the growing crops as needed.

Soybeans, oats, and alfalfa, in that order, were grown and harvested while in the vegetative stage of growth. The plant material was dried, ground, and the replicates composited. An aliquot for chemical analyses was then taken from each composited sample.[3] Protein, crude fiber, and ash analyses were run by standard A.O.A.C. methods. A modification of the procedure published by Mathis (4) was used for the spectrographic determination of *phosphorus, iron,* and *calcium.*

Soil tests were made after the harvest of each crop. Then lime and fertilizer materials were added to re-establish original pH values and nutrient levels.

EXPERIMENTAL RESULTS AND DISCUSSION

Under usual conditions, the plant constituents of most importance from the nutritional aspect and probably in order of importance are protein, phosphorus, calcium, crude fiber, iron and ash. Although other chemical constituents play important roles in nutrition, these six are most likely to be limiting factors in animal growth and health. Therefore, since space does not permit a discussion of the effects of the various soil treatments upon the concentrations of all the chemical constituents determined, this discussion is limited to these six.

Effects of Lime

The data presented in *table 1* show that lime caused marked changes in the composition of soybeans. As indicated by the correlation coefficient "r", percentage of phosphorus was decreased and those of all other constituents were increased by applications of lime. The reduction in phosphorus and the increase in crude fiber occurred as a result of the first increment of lime, while calcium and ash percentages increased again with application of the second lime increment. Plant protein percentage increased consistently with each step rise in soil pH, irrespective of liming material, while the rise in percentage of iron was more consistent in the plants grown on calcium carbonate treated soils.

Probably the only significant difference that resulted from varying the liming material was in percentage of calcium. As would be expected, plant calcium percentage rose higher where the material was entirely calcium carbonate.

Each percentage recorded in *tables 1, 2 and 3* is an average of the test results on all plants grown at that pH level, regardless of the phosphorus and potassium levels. In addition to the calculation of correlation coefficient, the coefficient of likelihood was calculated (see Croxton and Cowden (2)). This latter coefficient indicates the significance of the variations between the standard deviations of the items that were included in the percentages given in the table. For instance, in *table 1,* the protein content of soybeans at pH 4.7 was 17.16 percent. The figure is an average made up of test results from plants that varied in phosphorus level and in potassium level. A significant coefficient of likelihood shows that standard deviations among those figures did vary, which indicates that phosphorus and potassium level differences affected the results. Thus, differences caused by lime treatments would need to be greater to bring about a significant "r". In *table 1* "L" was highly significant for all constituents except crude fiber and ash.

Oats were not greatly affected by lime. As shown by *table 2,* only calcium percentage was significantly increased, while percentage of iron was significantly decreased, the "r" value being negative. "L" was only significant for ash and iron which shows that for most constituents the data which made up the percentages were quite consistent.

[3]The authors are indebted to the Agricultural Chemistry Department for the chemical analyses of the plant material.

TABLE 1—The effect of lime on the feed constituents of soybeans

Treatment		Constituent percentage in dry tissue[1]					
Material	pH	Protein	Phosphorus	Calcium	Crude fiber	Ash	Iron
None	4.7	17.16	.584	1.12	18.70	6.11	.0097
$CaCO_3$	5.8	18.69	.260	1.43	21.08	6.38	.0090
$CaCO_3$	6.3	19.59	.323	1.80	21.73	6.59	.0112
$CaCO_3$	6.8	20.93	.294	1.82	21.34	6.57	.0125
$CaCO_3+MgCO_3$	5.8	18.86	.304	1.46	20.74	6.38	.0094
$CaCO_3+MgCO_3$	6.3	19.40	.317	1.55	21.17	6.21	.0107
$CaCO_3+MgCO_3$	6.8	20.24	.265	1.53	20.68	6.34	.0122
r[2]		**[4]	—**	**	**	*	*
L[3]		**	**	**			**

[1]Percentages are averages of the tests made on all plants grown at the same pH level, disregarding phosphorus and potassium levels.
[2]r = correlation coefficient.
[3]L = coefficient of likelihood.
[4]Two stars—significant at 1% level; one star—significant at 5% level.

TABLE 2—The effect of lime on the feed constituents of oats

Treatment		Constituent percentage in dry tissue[1]					
Material	pH	Protein	Phosphorus	Calcium	Crude fiber	Ash	Iron
None	4.7	10.42	.395	.268	28.97	7.46	.0392
$CaCO_3$	5.8	9.61	.298	.264	28.95	6.82	.0073
$CaCO_3$	6.3	10.38	.296	.425	28.83	6.85	.0066
$CaCO_3$	6.8	10.80	.249	.359	29.31	6.76	.0087
$CaCO_3+MgCO_3$	5.8	9.52	.298	.276	29.15	6.93	.0071
$CaCO_3+MgCO_3$	6.3	10.08	.355	.384	29.05	6.90	.0120
$CaCO_3+MgCO_3$	6.8	10.71	.314	.465	29.24	6.69	.0089
r[2]				**[4]			—**
L[3]						*	**

[1]Percentages are averages of the tests made on all plants grown at the same pH level, disregarding phosphorus and potassium levels.
[2]r = correlation coefficient.
[3]L = coefficient of likelihood.
[4]Two stars—significant at 1% level; one star—significant at 5% level.

TABLE 3—The effect of lime on the feed constituents of alfalfa

Treatment		Constituent percentage in dry tissue[1]					
Material	pH	Protein	Phos-phorus	Calcium	Crude fiber	Ash	Iron
None..........	4.7	18.74	.494	1.62	—	—	.0609
$CaCO_3$.........	5.8	18.83	.293	2.19	23.15	9.94	.0409
$CaCO_3$.........	6.3	19.44	.338	2.36	22.92	9.85	.0482
$CaCO_3$.........	6.8	19.14	.350	2.57	23.06	10.66	.0491
$CaCO_3+MgCO_3$.	5.8	19.33	.301	1.90	23.47	9.21	.0360
$CaCO_3+MgCO_3$.	6.3	19.45	.294	1.92	23.00	10.11	.0460
$CaCO_3+MgCO_3$.	6.8	19.86	.297	1.98	22.49	9.30	.0376
r[2]		*[4]		**		—*	
L[3]		**	*			**	*

[1]Percentages are averages of the tests made on all plants grown at the same pH level, disregarding phosphorus and potassium levels.
[2]r = correlation coefficient.
[3]L = coefficient of likelihood.
[4]Two stars—significant at 1% level; one star—significant at 5% level.

The composition of alfalfa was not greatly changed by applications of lime. *Table 3* shows that protein percentage was increased significantly to the 5 percent level and calcium to the 1 percent level but percentage of ash was actually decreased. That the apparently large increase in phosphorus brought about by the first increment of $CaCo_3$ was not significant is probably the result of wide variations in the data used to obtain the averages.

Effects of Phosphorus

Variations in phosphorus levels affected the three crops differently. In the case of soybeans, as shown in *table 4*, percentages of four constituents (protein, phosphorus, crude fiber, and ash) were increased. The increases in protein were consistent as the levels of soil phosphorus were raised from 30 to 60 to 90 pounds an acre. This is interesting since 60 pounds an acre in a field soil has been considered high. It is also interesting that plant phosphorus did not increase as soil phosphorus was raised from the high to the very high levels. It seems that this should have happened, as it did to a very marked degree in the case of oats and to some extent with alfalfa.

Changing phosphorus levels affected the protein content of oats in exactly the opposite way that it did that of soybeans. Increases in soil phosphorus caused a consistent and highly significant decrease in protein and a significant decrease in percentage of iron.

The calcium content of oats is always very low. The highest soil phosphorus level resulted in a plant calcium level of 0.460 percent as compared with a percentage of 0.309 in oats grown at the low level. The increase seems questionable however, because the intermediate soil phosphorus level did not appear to bring about the proper intermediate level of plant calcium.

In the third crop, alfalfa, phosphorus had no effect on percentage of protein, calcium, and crude fiber (*table 4*). As already mentioned, plant phosphorus per-

TABLE 4—The effect of phosphorus on the feed constituents of soybeans, oats, and alfalfa

Soil phosphorus	Constituent percentage in dry tissue[1]					
Pounds per acre	Pro-tein	Phos-phorus	Cal-cium	Crude fiber	Ash	Iron
Soybeans						
30	17.72	.279	1.51	20.79	5.74	.0113
60	19.90	.393	1.52	20.57	6.49	.0107
90	21.18	.392	1.49	21.17	7.14	.0098
r[2]	**[4]	**		*	**	
L[3]	**	**	**			**
Oats						
30	10.38	.252	.309	29.35	6.87	.0094
60	9.86	.279	.276	29.10	6.82	.0086
90	9.44	.439	.460	29.01	6.81	.0087
1	— **	**	**			— *
L						**
Alfalfa						
30	19.09	.274	1.87	22.97	9.33	.0388
60	19.42	.360	2.18	23.00	9.65	.0428
90	19.16	.389	2.09	23.09	10.61	.0542
r		**			*	*
L	*	*	*		**	**

[1]Percentages are averages of the tests made on all plants grown at the same levels of phosphorus, disregarding potassium level and pH.
[2]r = correlation coefficient.
[3]L = coefficient of likelihood.
[4]Two stars—significant at 1% level; one star—significant at 5% level.

centage was increased very significantly and ash and iron increases were significant to the 5 percent point. There was no indication that content of plant protein correlated with soil phosphorus levels and only a slight indication that calcium percentage was affected by the varying phosphorus levels. It should be remembered, of course, that only the first alfalfa crop was analyzed.

Effects of Potassium

The experimental potassium levels were 100 pounds, low for field soils, 200 pounds, and 300 pounds an acre, the latter very high for field soils. In the case of soybeans the correlation with protein percentages was negative. The "r" value was significant but because the data were not consistent they probably should not be considered as significant. Exactly the same situation occurred with respect to ash percentage except the apparent correlation was positive. In other words, potassium probably had no real effect on the composition of soybeans (*table 5*).

TABLE 5—The effect of potassium on the feed constituents of soybeans, oats, and alfalfa.

Soil potassium Pounds per acre	Constituent percentage in dry tissue[1] Pro- tein	Phos- phorus	Cal- cium	Crude fiber	Ash	Iron
Soybeans						
100	19.71	.361	1.54	20.87	6.33	.0109
200	19.15	.345	1.48	20.82	6.28	.0107
300	19.94	.357	1.51	20.84	6.76	.0101
r[2]	— *[4]				**	
L[3]				*		*
Oats						
100	10.00	.316	.349	29.20	6.28	.0112
200	9.69	.333	.362	29.26	6.85	.0079
300	9.99	.321	.334	29.00	7.31	.0077
r	— **				**	— *
L				**	**	**
Alfalfa						
100	18.93	.383	2.47	23.30	9.42	.0453
200	19.40	.347	1.96	22.69	10.10	.0442
300	19.34	.292	1.70	22.90	10.07	.0463
r	**		— **	— *		
L	*		**		**	

[1]Percentages are averages of tests made in all plants grown at the same levels of potassium, disregarding phosphorus level and pH.
[2]r = correlation coefficient.
[3]L = coefficient of likelihood.
[4]One star—significant at 5% level; two stars—significant at 1% level.

The protein content of oats was affected by soil potassium levels in much the same way as was that of soybeans. The negative correlation was highly significant but the data were not consistent, first falling, then increasing. As a result their dependability should be questioned.

The most consistent differences (a highly significant negative correlation) caused by varying soil potassium levels were in alfalfa calcium percentages. The plants grown where the level was 100 pounds an acre contained 2.47 percent calcium while that grown where the soil level was maintained at 300 pounds was down to 1.7 percent.

DISCUSSION

The data presented in this paper show definitely that plant composition, with respect to protein, phosphorus, calcium, crude fiber, ash and/or iron may be changed by applications of lime and by varying the levels of available soil phosphorus and potassium. The changes brought about by treatment varied, however, with the crop under consideration. Furthermore, with any given crop, some constituents were increased while others were decreased by the same treatments.

This means that the quality of a forage as a feed crop may, by treatment, be improved in some respects and injured in others. For instance, lime improved the feeding quality of soybeans by increasing percentages of protein, calcium, ash, and iron but lowered their value by reducing plant phosphorus and by increasing their percentage of crude fiber. Whether the forage would be more or less valuable as animal feed would depend upon the species and age of the animals and upon the nature and composition of other feeds included in the ration. For instance, if a protein supplement is included in a ration, the importance of plant protein level is less marked. Also it must be realized that changes in plant composition do not necessarily indicate changes in the nutritive value of plants. For example, Mitchell, *et al.* (5) found that increasing the protein content of corn did not increase its feeding value unless it was supplemented with lysene and tryptophane. The high protein corn was as deficient in these essential amino acids as was the low protein corn.

The results of these greenhouse pot tests seem to bear out a conclusion already drawn with respect to the nutrition farm study; namely, that a completely balanced fertilizer may not appreciably change plant composition. As illustration, applications of lime increased plant protein in two crops but not in a third. Increasing phosphorus levels caused a protein increase in one crop, a reduction in one crop, and had no effect in a third. Lime applications brought about increase in plant calcium in all crops but there was a tendency for high potassium in the soil to reduce the level of calcium in the plant.

Lime applications reduced phosphorus percentages in all of the crops studied. The correlation was highly significant in the case of soybeans. It is doubtful, however, if this would occur where all the plants tested were grown on soil which contained high levels of available phosphorus. This conclusion must be drawn from the data regarding the correlations between soil phosphorus levels and percentages of phosphorus in soybeans, oats, and alfalfa.

Crude fiber has been used as an indication of feeding quality. On the whole, the treatments had very little effect on the percentages of this constituent. Lime caused crude fiber to increase in soybeans but had no effect on that constituent in oats or alfalfa. In correlating phosphorus levels with crude fiber percentages, "r" was significant only with soybeans and, with potassium levels, a significant negative correlation occurred with alfalfa. In no crop did potassium increase crude fiber content.

SUMMARY

Soybeans, oats, and alfalfa plants were grown in the greenhouse in soil which varied in pH, available phos-

phorus, and available potassium. Treatments were arranged in a factorial design. Chemical analyses were made on the plants for protein, phosphorus, calcium, crude fiber, ash and iron.

Liming markedly changed the composition of soybeans but had much less effect on alfalfa and very little effect on oats. In the soybeans, the lime decreased the percentage of phosphorus but caused increases in the percentages of all the other constituents studied. Thus lime probably improved the feeding value of the soybeans, especially if they were to be fed in a ration which included another source of phosphorus. Lime increased plant calcium in all the crops.

The content of plant phosphorus in all three crops correlated directly and significantly with levels of available soil phosphorus. The effect of the phosphorus levels on the other constituents varied with the crop.

Potassium fertilization caused only minor changes in the percentages of the constituents in the plants.

Unbalanced nutrient levels caused changes in plant composition but the changes varied with the crop. Furthermore, the effect which such changes might have on the nutritive value of the feeds would depend upon the animal being fed and upon the composition of the other feeds included in the ration.

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Effects of Growth Regulators On Plant Composition

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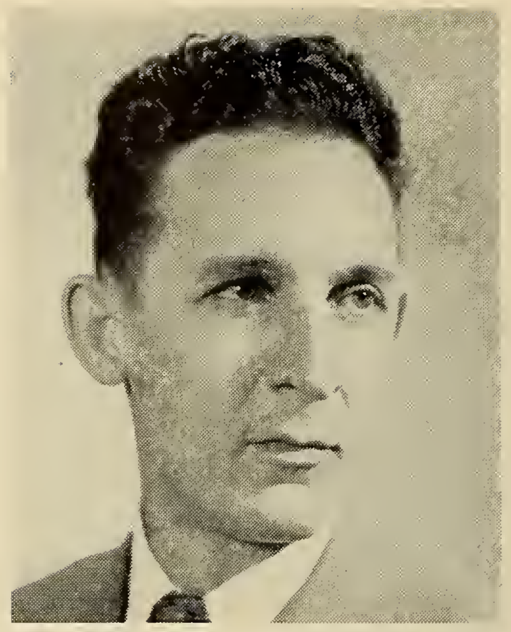

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INTRODUCTION

SINCE THE DAWN OF RECORDED HISTORY, one of man's principal objectives has been the control of plant growth. He soon learned that the promotion of lush vegetative growth did not always produce the best in fruit and seed. There evolved cultural practices such as pruning and the application of fertilizer to regulate quality as well as quantity of growth. Since the fairly recent discovery of hormones in plants, growth regulation by chemicals in minute quantities is rapidly becoming a part of our agricultural economy. One of the most important of these, 3-indoleacetic acid (IAA) was first synthesized by Ellinger (24) in 1904 by heating the phenylhydrazone of β-aldehydopropionic ester. This compound, destined eventually to exert a tremendous influence in crop production and marketing, then remained unnoticed for almost 30 years. After its isolation from urine and plants in 1934 by Kögl, *et al.* (79, 80), numerous agricultural uses have been discovered for structurally related chemical regulators of plant growth. Intimately associated with their usefulness for the encouragement of roots on cuttings, the hastening of fruit maturity, the delay of fruit maturity, the control of fruit drop, as sprout inhibitors and as selective herbicides are accompanying changes in the composition of the plant parts affected. Often the effectiveness of the growth regulator for inducing a specific response is conditioned by the degree to which food reserves are available and are mobilized or demobilized in various organs. Most chemical plant regulators *per se* as they might occur as residues in treated plants have been found relatively non-toxic to man and warm-blooded animals. Since the effects of these chemicals as they alter the metabolism of intact plants and induce changes in composition are frequently pronounced, they deserve more consideration. Visible changes induced in morphology, growth, maturity, and color in edible portions of a crop may be accompanied by changes in chemical composition. As yet this aspect has received only scant attention. It is in this area, in recent years, that the plant physiologist has begun to cooperate with the biochemist to acquire at least a few elementary facts.

ROOTING OF CUTTINGS AND SETTING OF FRUIT

Two of the earliest uses of chemical growth regulators that have achieved considerable significance are the rooting of cuttings and the promotion of fruit set. Both of these responses are accompanied by an altered metabolism in the treated parts. The changes in composition normally associated with root initiation (11, 22, 157) and fruit growth are accelerated by the appropriate chemical, and the ease with which roots will form and fruit will set is often dependent upon a source of carbohydrate and protein that can be readily hydrolyzed to yield simpler compounds. Essentially the changes in composition accompanying the use of growth substances for rooting of cuttings and setting of fruit are those that happen normally at a later date, perhaps, when these growth responses would occur in the absence of externally applied chemical stimuli. In this connection the detailed studies of Marré and co-workers (89, 90, 91) have shown that the chemical changes induced in tomato ovaries and corn kernels following treatment with the ethyl ester of 3-indoleacetic acid (Et-IAA), 4-chlorophenoxyacetic acid (ClPA), and α-naphthaleneacetic acid (NA) are

TABLE 1—Comparative composition of Rutgers tomatoes induced to develop by chemical treatment and from normal pollination (per cent of fresh weight)

Constituent	Chemically set fruit	Normal fruit
Total solids	6.90	6.80
Carotene (ppm)	55.00	53.00
Ascorbic acid	0.02	0.02
Nitrogen	0.20	0.19
Total sugars	2.08	2.04
Reducing sugars	1.99	1.94
Ash	0.63	0.65

Data from Palmer (116).

strikingly similar to those affected by normal pollination and fertilization. Furthermore, the similarity in chemical composition of the parthenocarpic or so-called seedless fruit with that of the normal seeded fruit continues to maturity. The investigations of Holmes, *et al.* (67), Palmer (116) and others (102, 108) show that tomatoes influenced to set by chemical means do not differ in either organic or inorganic constituents from those developing after normal pollination (*tables 1 and 2*). Similar results have been reported for snap beans (116), strawberries (181), blackberries (182), grapes (162, 165), figs (3, 16) and pears (54). In the stimulation of fruit set by growth regulators, any originally induced changes in chemical composition attended with an initial hastening of growth processes do not persist in maturing fruit, even though physical characteristics associated with the absence of seed may be apparent.

PRE-HARVEST AND POST-HARVEST TREATMENTS OF FRUITS AND VEGETABLES

Following the first report of the chemical control of apple drop by Gardner, *et al.* (43) in 1939 were the observations that the pre-harvest and post-harvest coloring, rate of ripening, and subsequent storage life

TABLE 2—Comparative mineral nutrient composition of Rutgers tomatoes induced to develop by chemical treatment and from normal pollination (mg./kg. of fresh weight—spectrographic analysis)

Mineral nutrient	Chemically set fruit	Normal fruit
Potassium	3,700	2,900
Phosphorus	330	340
Magnesium	130	110
Calcium	86	78
Iron	6	7
Sodium	4	3
Zinc	3	4
Manganese	2	2
Molybdate	0.2	0.3

Data from Palmer (116).

were influenced. Some of these induced effects on maturity and color development that alter the storage and shelf life of many fruits other than the apple as well as certain vegetables are receiving considerable recognition. Accompanying differences in composition following treatment of the fruit are common.

Some hastening of maturity on the tree and ripening in storage has been reported after pre-harvest treatment of apples and pears with NA as a stop-drop spray (46); however, other growth substances including 2,4-dichlorophenoxyacetic acid (2,4-D), 2,4,5-trichlorophenoxyacetic acid (2,4,5-T), and 2,4,5-trichlorophenoxypropionic acid (2,4,5-TP have had a much more pronounced effect (1, 6, 23, 29, 75, 153, 154, 159, 160, 168, 169.) Greater and more uniform color development and somewhat more rapid maturity in both apples and pears follows the use of 2,4,5-TP for the control of pre-harvest drop, while 2,4,5-T and in some instances 2,4-D will greatly accelerate ripening.

Usual changes in fruit composition associated with the stop-drop sprays include greater pigmentation, an increase in sugars or soluble solids, a decrease in starch and a conversion of insoluble forms of pectin to soluble forms. These changes in chemical composition are accompanied by an increase in respiration. Similar effects from 2,4-D applied to detached fruits have been reported (64, 103, 152).

Since accelerated ripening and accompanying changes in composition associated with the use of growth regulators as stop-drop sprays are sometimes undesirable, a possible solution lies in their use in combination with maleic hydrazide (MH), which negates their ripening effect but does not interfere with their stop-drop properties (150, 151).

If 2,4,5-T is applied on immature attached fruit, a remarkable hastening of ripening has been reported. Green Calimyrna figs 45 days old have been induced to mature in 60 days rather than the usual 120-day period (7). The chemically ripened fruit is comparable in quality, flavor and chemical composition. It is suggested that the fruit ripens earlier because the growth regulator hastens the mobilization of food reserves into the fruit. This is possible in the fig where ample food reserves are present, and also to a lesser degree in apricots (14, 15), apples (92), grapes (164), peaches (166), and prunes (180) where somewhat more limited food reserves are available. If fruit are harvested simultaneously from treated and non-treated plants, the former are generally higher in moisture content and soluble solids and show greater color development. Whereas certain growth regulators may accelerate the mobilization of food reserves into the developing fruit and promote earlier ripening, the induced changes in composition are essentially the same as in those that mature normally.

Plant regulators may also change the morphology and chemical composition of fruits and vegetables and

flower parts resulting in delayed maturity, longer shelf-life and increased vitamin content. Thus, 4-chlorophenoxyacetic acid (ClPA) applied to pineapple prior to harvest reduces physiological breakdown resulting from cool temperatures. At the same time, treated fruit contain significantly greater quantities of ascorbic acid (95). In the pineapple exposure of the fruit to cool temperatures results in the destruction of ascorbic acid; ClPA seems to prevent such destruction to the extent that increases of over 100 percent have been noted.

The sparing effect of ClPA on vitamin C in pineapple has a counterpart in snap beans. An aqueous solution containing 100 ppm sprayed on snap beans 4 days before harvest has resulted in the maintenance of a higher vitamin C content in the pods subsequent to harvest (106), and a higher moisture content and water-retaining capacity (107).

Griesel (53) has demonstrated that maleic hydrazide (MH) applied to flowers of *Magnolia grandiflora* at an early stage of bloom retards their aging. Abscission and aging of the perianth segments was found directly related to the loss of starch from the flower parts. Maleic hydrazide retarded the rate of starch digestion and thus in a remarkable manner prolonged the life of the flowers. A similar effect of preharvest sprays of MH on preserving the starch content of Butternut squashes, with no change in other nutritive constituents, has been reported by Holmes, *et al.* (68). The rate of loss of starch was greatly depressed. The chemical treatment not only conserved the food value but lengthened the effective storage life of the squashes. According to Erickson, *et al.* (30), MH applied at 100, 500, and 1000 ppm, 49 days before the harvest of oranges and grapefruit increased the soluble solids in the juice in direct proportion to the concentration of MH.

General delays in maturity of fruit from growth regulators applied prior to harvest include limes (28), oranges and grapefruit (30), snap beans (59, 156), raspberries (73), and grapes (163). The accompanying differences in composition are directly associated with the chemically induced immaturity. This has occurred in some instances with the same growth regulators that hasten maturity in other crops.

INHIBITION OF SPROUTING

Growth regulators have been used extensively as sprout inhibitors in the storage of potatoes. Pre-harvest and post-harvest treatments with such diverse chemicals as the methyl ester of α-naphthaleneacetic acid (18, 19), 2,4-D (149), isopropyl N-phenylthiocarbamate (45), tetrachloronitrobenzene (171), and maleic hydrazide (118) effectively retard storage growth with no apparent adverse effects on quality or composition.

Conversely, detailed tests with MH as a pre-harvest spray for control of sprouting of sugar beets have shown that the sucrose content of the beets at harvest is significantly greater (124, 139, 174). The sugar yield per acre is also increased if spray treatments are properly timed (94, 138). Sugar loss of MH treated beets during storage was less and this was accompanied by a lowering of respiratory activity. In contrast, 2,4-D and related compounds have greatly depressed the sucrose content and sugar yields (115, 126).

In the storage of onions pre-harvest treatment with MH not only offers a complete control of sprouting but preserves the original sugar content of the bulbs (119). With carrots no significant effects on composition have been detected with the possible exception that the Kjeldahl nitrogen was slightly higher in treated lots (172). In the radish a significant increase in soluble solids (sugar) and firmness of the hypocotyl follows treatment with MH and these differences persist during storage (69). This favorable effect on composition and the advantage of growth control in the pre-package product (21) will likely foster the widespread use of the chemical in the future marketing of radishes.

Properly timed pre-harvest applications of MH on a great number of varieties of potatoes (74, 128) not only offer a practical control of storage sprouting but also may improve the edible quality. Under certain conditions the specific gravity is greater (37, 140) and the percentage of reducing sugars is less (118). When the treated potatoes are processed as chips, an improvement in color has been reported (140). Treatment of the sweetpotato with MH has resulted in a decreased carotene content following storage (31).

HERBICIDES—WITH SPECIAL REFERENCE TO 2,4-D

The application of sublethal concentrations of 2,4-D associated with its herbicidal use may produce marked alterations in the physiology and chemical composition of plants. As reviewed by Stahler and Whitehead (155), 2,4-D in the pure form or the amount sprayed on pasture grasses for weed control has not been found toxic to livestock. Cattle also graze 2,4-D sprayed and unsprayed areas indiscriminately. Instances have been reported where cattle relish some weeds that are normally not eaten after treatment with 2,4-D. According to one report, field mice also preferred corn seedlings from plots treated with pre-emergence applications of 2,4-D (127). Treatment with 2,4-D has likewise resulted in an increase in sugar cane borer infestation (70). Grasses have become temporarily darker green in color (105).

The accumulation of certain toxic products in the plant following the increasingly widespread application of 2,4-D to crops has been proposed as an explanation of its phytotoxicity, and has been a subject attracting considerable attention from the standpoint of animal and human nutrition. Fults and Johnson (40) found that plants after treatment with

TABLE 3—Effect of 2,4-D on protein content of wheat

Amount of 2,4-D applied (lbs. acre)	Protein content (percent)
0.0	10.9
0.6	11.6
1.4	12.7
2.0	13.8
4.6	15.5

Data from Erickson, Seely and Klages (27).

2,4-D have more anthocyanin and scopoletin. The report of Stahler and Whitehead (155) that sublethal dosages of 2,4-D indirectly increased the potassium nitrate content of sugar beet leaves by twenty-fold prompted extensive investigations, since ingestion of forage containing large amounts of nitrates by animals often results in the reduction of the nitrates to nitrites by micro-organisms in the animal rumen. Excessive nitrites in the blood stream may reduce the hemoglobin to methemoglobin, which reduces the oxygen carrying capacity of the blood as well as its release, and may result in death of the animal from asphyxiation.

However, the results of Stahler and Whitehead have been only partially confirmed by others. Fertig (34, 35) and Berg and McElroy (4) obtained only moderate increases in nitrate content in some weeds and crops following treatment with 2,4-D. The greatest increases occurred 1 to 3 days after treatment with plants that inherently accumulate large quantities of nitrate nitrogen. These increases in nitrate content of forage were not considered hazardous to livestock grazing on treated areas.

More recent analytical studies (20, 42, 56) on a wide variety of plant species following herbicidal use of 2,4-D on pastures rather conclusively demonstrate that there is no effect on either nitrate or total nitrogen contents. Reports (55, 85) further indicate no significant influence in the hydrocyanic acid content of the leaves of the wild black cherry (*Prunus serotina*), and that the potential danger to cattle and sheep grazing on wild cherry leaves is not enhanced following treatment with 2,4-D or 2,4,5-T as brush killers (57).

In a study of the effects of 2, 4-D on the hydrocyanic acid and nitrate nitrogen content of sudan grass, Swanson and Shaw (158) reported in greenhouse tests that 2,4-D suppressed the accumulation of hydrocyanic acid, while in the field there was an initial suppression followed by an increase to levels significantly higher than the controls. In respect to nitrate content, there was an initial increase followed by a rapid and significant decrease. The contents of hydrocyanic acid and nitrates were inversely related, and it was concluded that in sudan grass 2,4-D may change the ratio of oxidized to reduced nitrogen.

The effect of 2,4-D as a weed killer in potato fields has prompted studies concerning its effect on tuber quality. Fults, *et al.* (41) claimed that the nitrate content of Red McClure potatoes remained unchanged upon treatment with 2,4-D. However, Payne, *et al.* (122) have reported an increase in protein content following an application of one-half pound of 2,4-D per acre. Associated with the increase in protein content was an increase of free glutamic acid and a decrease in eleven other amino acids (120, 121).

Alterations in nitrogen metabolism of wheat treated with 2,4-D for weed control are reflected in changes in protein content. Erickson, *et al.* (27) significantly increased the percentage of crude protein in wheat plants by treating with 2,4-D (*table 3*) Helgeson, *et al.* (65) found that the protein content of bread wheats was slightly greater when treated with 2,4-D esters while the protein content of durum wheat was decreased by the amine and sodium salts. Klingman (77) found that protein percentage was inversely associated with yield and when no changes occurred with treatment, 2,4-D had no effect upon protein content in winter wheat. Significant increases in protein have been reported (8, 125, 143), but with no increase in protein yield per acre. Willard (170) suggests that, whereas, protein in wheat may be increased 50 percent by application of 2,4-D as a post-emergence spray for weed control, it is at the expense of yield. He further indicates that 2,4-D increases the protein content of wheat in a manner similar to the effects of drought or black stem rust infection; the nitrogenous parts of the grain are laid down first, and anything that reduces "filling" of the grain increases protein content. In general, the milling and baking qualities of wheat are not affected by 2,4-D applications for weed control (12, 39, 144).

The extreme sensitivity of cotton to 2,4-D makes weed control with this and related chemicals a hazard in areas where it is grown. Cotton treated with physiologically tolerable quantities (1.1 m/g plant) of 2,4-D showed no appreciable differences in physical properties of the lint or chemical composition of the seed except that the free fatty acid content in the seed was greatly reduced (88). On the other hand, Epps (25) has reported that in instances where 2,4-D reduced the yield of cotton, the oil content of the seed was also proportionately reduced. Ergle and Dunlap (26) found that increasing applications of 2,4-D raised the concentrations of sucrose, hemicellulose and cellulose in the main stalk of cotton plants while reducing and total sugars and total organic acids varied inversely to the amount applied. The starch content of leaves was only affected at the highest rates.

A study by Rebstock, *et al.* (132) on the effects of the herbicide, sodium trichloroacetate (TCA), on the composition of wheat seedings deserves mention. Following treatment of the soil with the equivalent of 30 pounds per acre of TCA the shoots contained a higher percentage of crude protein, arginine, acid-hydrolyzable polysaccharides and reducing sugar. A decrease was

observed in the percentage of non-reducing sugar, ether extract, unsaponifiable material, fatty acids and tryptophan. The roots showed a slight increase in the percentage of crude protein, amino acids, reducing sugar and starch while the percentage of non-reducing sugar and ether extract did not change. Respiratory activity was greater in both the shoots and roots of plants grown in the treated soil.

EFFECT OF METABOLIC DISTURBANCES

Much emphasis and speculation has been advanced concerning the possible role of growth regulators in plants. All plant regulators applied at high concentrations cause the metabolism to be disturbed but not all are sufficiently phytotoxic to be effective herbicides. 3-Indoleacetic acid and α-naphthaleneacetic acid are plant regulators of the latter type since their herbicidal action is much lower than 2,4-D.

Two approaches as to the mechanism of action of plant regulators have been used. One has been concerned with the changes made by the regulator upon the structure and organization of the cell as seen under the microscope, and the other involves a study of induced changes in the chemical constitution of the cell or tissue.

3-Indoleacetic acid (IAA): To comprehend the function of synthetic and natural plant regulators, it is necessary to have an understanding of the action of 3-indoleacetic acid now regarded as a natural hormone (5, 60, 61, 134). This naturally occurring regulator apparently exerts its effect on growth and respiration through the metabolism of phosphate (9, 10), which is involved in the transfer of energy (93). Hence, IAA can regulate the flow of energy for various other reactions in the plant (136). Nucleic acids (145) accumulate in the pith tissue of tobacco plants treated with IAA, which suggests that phosphorus is mobilized in this fraction. Other metabolic disturbances such as alterations in simple sugars (2, 48, 49, 90, 97, 99, 101, 146, 148), starch (2, 90, 97, 101), acetaldehyde (109), nitrogen (97, 99, 148), nitrate nitrogen (36), minerals (11), and dry weight (97, 98) have been observed in various plants. King (76) found that the α-amylase activity was increased in germinating wheat seeds grown in solutions of IAA while Mitchell and Stuart (99) indicated a higher proteolytic enzyme activity in bean cuttings. These results may explain the accelerated rate of hydrolysis of starch (2, 101) and the accumulation of nitrogen (97, 99) in plants treated with IAA. Similar effects on metabolism of plants have been recorded for α-naphthaleneacetic acid (22, 96, 100, 101).

2,4-Dichlorophenoxyacetic acid (2,4-D). A considerable number of papers have been published on the physiological action of 2,4-D on plants but few controlled experiments have yet appeared in which composition was studied. Some information has, however, been derived from circumstantial evidence available from field experiments. Two of the most pronounced metabolic effects of 2,4-D on plant composition are the accumulation of nitrogen (13, 38, 58, 78, 142, 147, 176) and the rapid depletion of carbohydrates (44, 129, 142, 147) especially in stem tissue. This has been attributed to their utilization in accelerated respiration (129, 147). On the other hand, Gunar, *et al.* (58) reported an increase in the soluble carbohydrates and a decrease in the ratio of protein to non-protein nitrogen in the sunflower. Youngken (179) concluded from his studies that 2,4-D did not have any effect on the alkaloidal nitrogen content of *Datura stramonium*. Weller, *et al.* (167) applied 2,4-D solutions (1000 ppm) to red kidney bean plants and 6 days after treatment observed reduced percentages of protein, non-reducing sugars and most of the amino acids in the leaves and roots (*tables 4, 5*). No significant changes were noted in the leaves and roots for reducing sugars, starch, acid hydrolyzable polysaccharides, crude fiber, ether extract, unsaponifiable material, and total ash. In the treated bean stem tissue, Sell, *et al.* (142) observed a pronounced proliferation of the tissue which was accompanied by an increase of protein and amino acids (*table 4*). Reducing and non-reducing sugars were exhausted while ash, ether extract, unsaponifiable material and fatty acids increased (*table 5*). Rebstock, *et al.* (131) extending these studies found that the major portion of the accumulated nitrogen was in the protein fraction and not due to the formation of free amino acids (*table 6*). The tremendous increase of protein in the stem tissue may be accounted for in part by the translocation of some of the amino acids from the roots and leaves and the conversion of the sugars into proteins. Carbohydrates may also be depleted by an accelerated respiration as reported by Smith, *et al.* (147) and Rasmussen (129).

TABLE 4—Effect of 2,4-D on the protein and amino acid content of the leaves, stems and roots of red kidney bean plants (dry weight basis)

Constituent	Leaves		Stems		Roots	
	Control (%)	Treated (%)	Control (%)	Treated (%)	Control (%)	Treated (%)
Protein (N x 6.25)	31.1	29.8	16.9	30.5	22.7	22.4
Leucine	2.2	2.0	0.7	1.4	1.0	1.0
Isoleucine	1.6	1.5	0.8	1.6	1.0	0.9
Valine	1.8	1.6	0.7	1.8	1.1	1.1
Phenylalanine	1.5	1.3	0.5	1.0	0.6	0.6
Histidine	0.9	0.7	0.4	0.8	0.4	0.4
Arginine	1.8	1.5	0.8	1.5	0.8	0.8
Lysine	1.4	1.3	0.5	1.5	1.0	0.8
Tryptophan	0.4	0.3	0.1	0.2	0.1	0.1
Methionine	0.3	0.2	0.1	0.2	0.2	0.1
Threonine	1.4	1.3	0.7	1.1	0.9	0.8
Aspartic acid	2.0	1.8	1.5	1.9	1.4	1.1

Data from Weller, *et al.* (167) and Sell, *et al.* (142).

TABLE 5—Effect of 2,4-D on the composition of the leaves, stems and roots of red kidney bean plants (dry weight basis)

Constituent	Leaves		Stems		Roots	
	Control (%)	Treated (%)	Control (%)	Treated (%)	Control (%)	Treated (%)
Reducing sugar....	0.0	0.0	1.7	0.0	0.2	0.0
Non-reducing sugar	1.0	0.0	4.8	0.0	1.8	0.0
Starch............	1.7	1.8	7.2	2.1	2.2	2.1
Polysaccharide.....	5.9	4.8	12.2	10.1	8.7	9.7
Crude fiber........	13.8	15.1	30.3	20.0	20.4	19.6
Ether extract......	3.1	2.7	1.6	2.3	1.5	1.4
Unsaponifiable...	1.4	1.5	1.0	1.3	.9	1.1
Fatty acids......	1.2	1.2	.6	1.0	.6	.4
Ash..............	17.5	18.4	11.4	16.0	16.5	18.7

Data from Weller, *et al.* (167) and Sell, *et al.* (142).

Luecke, *et al.* (84) have reported that an application of 1000 ppm of 2,4-D to the red kidney bean plant increased pantothenic acid in the leaves and reduced the amounts of thiamine, riboflavin, nicotinic acid and carotene, while in the stems these constituents were increased, except for carotene which was depressed (*table 7*).

Closely associated with induced metabolic changes is the effect of 2,4-D upon certain enzymes. The proteolytic activity (131) in the stem tissue of the treated plants was approximately 40 percent greater than the control (*table 8*). The reverse occurred in the leaves while a slight decrease in activity was observed in the roots. No enzymes that gave carboxypeptidase or amino peptidase activity were found in the immature bean plants. Dipeptidase activity was observed in both treated and non-treated plants. The lower proteolytic activity in the treated leaf tissue was not surprising since there is a slightly lower amino acid content in the treated leaves (131, 167). These results suggest that the accumulation of protein in the stem tissue (*table 4*) may be correlated with the accelerated rate of proteolytic activity.

Neely, *et al.* (113, 114) observed that the action of the α-amylase, β-amylase and phosphorylase was less in the stem of the treated plants (*table 8*). The decrease of α-amylase and phosphorylase may account for the depletion of the simple sugars, which, under normal circumstances presumably arises from the hydrolysis of starch. Pectin methoxylase activity was also greater in tissue treated with 2,4-D (114). The increase in pectin methoxylase may be associated with the breakdown of the protopectin in the cell walls of plants treated with 2,4D (177) and accelerated maturity and ripening of attached and detached fruits treated with this and related compounds. The primary cell wall contains protopectin which is water insoluble but which can be hydrolyzed into pectic acid (free of CH_3) and pectinic acid (partly methylated). Treatment with 2,4-D apparently stimulates pectin methoxylase activity and initiates the breakdown of protopectin which, in turn, results in a reduced tensile strength of the young primary wall. The latter is subsequently stretched by turgor pressure of the cell (177).

Among the effects of other enzyme systems, Goldacre (47) has reported that 2,4-D accelerated the rate of oxidation of IAA when added to a crude enzyme preparation from etiolated pea epicotyls. According to Kvamme, *et al.* (81) 2,4-D inhibited the action of wheat germ lipase, and Hagen, *et al.* (62) noted no inhibition of polyphenol oxidase, α-hydroxy oxidase or catalase but that castor bean lipase was depressed.

TABLE 6—Effect of 2,4-D on the soluble and insoluble nitrogen fractions of the stems of red kidney bean plants (dry weight basis)

	Control (%)	Treated (%)
Total nitrogen........................	3.1	4.8
Soluble nitrogen (amino acids, etc.)....	1.5	2.0
Insoluble nitrogen (proteins, etc.)......	1.6	2.8

Data from Rebstock, *et al.* (131).

TABLE 7—B vitamins and carotene in leaves and stems of red kidney bean plants treated with 2,4-D (dry weight basis)

Vitamin	Leaves		Stems	
	Control	Treated	Control	Treated
	(micrograms per plant)			
Thiamine..........	15.7	5.2	0.9	1.7
Riboflavin..........	15.2	12.0	0.7	1.1
Nicotinic acid.......	62.2	45.5	10.0	12.9
Pantothenic acid....	5.2	8.8	2.2	5.7
Carotene...........	200.6	94.3	2.5	1.6

Data from Luecke, *et al.* (84).

TABLE 8—Effect of 2,4-D on enzymes in the leaf and stem tissues of the red kidney bean plant[1] (dry weight basis)

Enzyme	Leaf Tissue		Stem tissue	
	Control	Treated	Control	Treated
Alpha amylase[2].....	0.0	0.0	31.8	5.0
Beta amylase[3]......	26.3	27.4	36.6	23.9
Pectin methoxylase[4]	3.0	8.1	7.6	16.1
Phosphorylase[5].....	3.7	0.6	9.0	5.7
Proteolytic activity[6].	1.8	1.0	1.8	2.5

[1]Figures are the average of 4 replications with the exception of the proteolytic enzymes which are the average of 2 replications. Data from Neely, *et al.* (113, 114) and Rebstock, *et al.* (131).

[2]No. of gm. of soluble starch dextrinized by the alpha amylase of 1 gm. of tissue in 1 hr. at 30° C.

[3]No. of gm. of soluble starch converted to maltose by the beta amylase of 1 gm. of tissue in 1 hr. at 30° C.

[4]No. of mg. of methoxyl (OCH_3) liberated from an excess of pectin by the pectin methoxylase of 1 gm. of tissue in 30 min. at 30° C.

[5]One unit of phosphorylase activity has been defined as the amount of enzyme which catalyzes the liberation of 0.1 mg. of inorganic phosphorus from D-glucose-1-phosphate in 3 min. at 38 C. at pH 6.

[6]No. of mg. of amino nitrogen liberated from hemoglobin by 1 gm. of plant tissue in 5 hrs. at 48° C.

The butyl ester of 2,4-D was inactive as a lipase inhibitor and had to be first hydrolyzed to the acid. Ravazzoni (130) has claimed an increased action of the phosphate enzymes in tomato plants treated with 2,4-D while in the flowers Yakushkina (178) found higher catalase but lower peroxidase activities. The reverse in catalase and peroxidase occurred in the leaves. A decrease in peroxidase was observed by Felber (33) following treatment of bean plants with 2,4-D.

Maleic Hydrazide (MH) Aside from the observed changes in composition from treatment of sugar beets and other crops with MH for sprout inhibition are reports of altered carbohydrate and mineral metabolism. Carbohydrates in the plant or storage organ tend to accumulate or be preserved (72, 119, 124, 138) and normal respiratory losses are reduced. Thus Naylor (110) has reported that following treatment of corn seedlings with concentrations of 500 to 4000 ppm of MH the sucrose content of the shoots was increased up to thirteen-fold and the accumulations were directly proportional to the concentrations of MH applied. Treated plants contained less glucose in the roots. Naylor and Davis (111, 112), Learner and Wittwer (82), Currier, *et al.* (17), McIlrath (86, 87), Goris and Bouriquet (50), and Greulach (51) have all reported higher amounts of either starch or sugar or both in specific organs of MH treated plants. In experiments where bean and tomato plants were alternately exposed to light and dark, Greulach (51) concluded that MH aparently does not block either starch synthesis or starch breakdown, although such an action has been proposed by Peterson and Naylor (123). It is evident that MH exerts its sparing action on carbohydrate destruction and exerts its inhibiting influence on plant growth through its retardation of respiration. This has been manifested in the reduction of sugar losses in the storage of onions (119) and beets (173), the reduced rate of starch breakdown in Magnolia flowers (53) and in Butternut squash (68). Since the MH molecule may resemble a normal metabolite in the Kreb's cycle, the action of certain dehydrogenases is inhibited (71, 112). In a recent report, Isenberg, *et al.* (71) have shown that MH is stimulatory to the respiration of onion bulbs at low dosages and inhibitory at high. Similarly, Paterson (117) has reported a stimulation of storage sprouting in potatoes following treatment with low levels of MH and the complete inhibition at high concentrations.

MINERAL NUTRITION

In studies of the effect of 2,4-D on phosphorus metabolism in bean plants, Loustalot, *et al.* (83) have shown 2,4-D promotes phosphate accumulation in the roots. Rebstock, *et al.* (133), however, report that increased phosphorus occurs in the stem tissue and is likely associated with the metabolism of nucleic acids. Fang and Butts (32) have produced evidence that 2,4-D treatments reduced the upward movement of radioactive phosphorus to the leaves and that the plant regulator modified the distribution and accumulation pattern of radioactive phosphorus in plants. The phosphorus appeared to be metabolized as some intermediate in the water soluble fraction.

In other studies of mineral nutrition, Hamner (63) found that bean plants treated with NA contained higher percentages of calcium, phosphorus and nitrogen, while Brunstetter, *et al.* (11) observed that with IAA potassium, magnesium and boron increased in the stems after 30 hours, phosphorus and copper after 48 hours, and iron and aluminum after 72 hours. Differences in calcium were not significant. Higinbotham, *et al.* (66) have described experiments where rubidium uptake was stimulated in excised pea hypocotyl segments by application of IAA. In soybean plants grown in sand cultures at different nitrogen levels and supplied with 20 ppm of 2,4-D, Wolf, *et al.* (175) found that potassium was less and calcium was greater in the leaves. The studies of Rhodes, *et al.* (135, 137) indicate a marked diminution of potassium in the aerial portions and an accumulation in the roots of tomato plants treated with sublethal amounts of 2-methyl-4-chlorophenoxyacetic acid (MCPA). Overall, the potassium in the plant was greatly lowered which suggested a specific inhibition of potassium absorption combined with impeded transport. In later studies (137) MCPA had no effect on potassium, calcium, and magnesium uptake. Schuffelen (141) observed that the absorption of sodium, potassium and calcium in oat plants was independent of low concentrations of growth substances.

The probable inhibitory effects of maleic hydrazide on plant respiration are reflected by reduced uptake of phosphorus (123) and water (161). Phosphorus deficiency symptoms are frequently induced in treated plants (111). That MH may reduce absorption of mineral nutrients by the roots is suggested by Greulach (52) who found that no growth substance would counteract MH induced inhibition in sunflower, tomato, or bean. However, a complete mineral nutrient solution sprayed on the leaves of treated plants at intervals, at least partially counteracted the growth inhibition by MH in all species.

SUMMARY

Associated with the use of growth regulators in crop production, a study of the changes induced in the chemical constitution of plants assumes considerable significance and could provide a key to the mechanism of growth substances and their role in plant, animal, and human nutrition. Biochemical studies of growth regulators used to induce rooting of cuttings, fruit set, and fruit maturity have revealed that changes in composition are essentially the same as those processes that occur naturally in the plant. The effect of the growth regulator is to hasten the mobilization of carbo-

hydrate and protein by hydrolyses to yield simpler forms to produce the above responses at an earlier date.

Alterations in the physiology and chemical composition of crop plants have been induced by the application of sublethal concentrations of 2,4-D associated with its herbicidal use. The protein content, but not protein yield per acre, of wheat and potatoes has been significantly increased. Pasture crops following 2,4-D treatments for weeds are often changed in their protein, nitrate nitrogen, and hydrocyanic acid contents, but detailed studies indicate no potential danger to cattle or sheep.

The most drastic metabolic disturbances that herbicidal (lethal) concentrations (1000 ppm) of 2,4-D have on plants is the accumulation of nitrogen and the rapid depletion of carbohydrates. This has been attributed to their utilization in an accelerated respiration. In the bean plant these disorders are far more pronounced in the stems than in the leaves or roots. The activity of certain enzymes has been found intimately associated with the effects of 2,4-D on plant composition. Pectin methoxylase and proteolytic activity are greatly increased, while alpha and beta amylase and phosphorylase are decreased.

Whereas plants treated with lethal dosages of 2,4-D quickly become depleted in carbohydrates, maleic hydrazide (MH), which is used as a sprout inhibitor for potatoes, onions, or sugar beets and in the storage of squash, exerts a sparing effect on carbohydrate utilization, and respiration, and may to some extent negate the effect of 2,4-D. The physiological responses and the stability in carbohydrate content induced in plants following treatment with MH are usually opposite to those of 2,4-D.

The effects of growth regulators on mineral nutrition and vitamin content of plants are diverse. A conservation of vitamin C has been reported in snap beans and pineapple following treatment with 4-chlorophenoxyacetic acid. Maleic hydrazide induces general phosphorus deficiency symptoms in plants and reduces the carotene content of sweet potatoes, while 2,4-D promotes phosphate uptake and may alter the B vitamins and carotene content of various plant tissues.

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The Effect of Fertilizers on the Nutritional Quality of Crops

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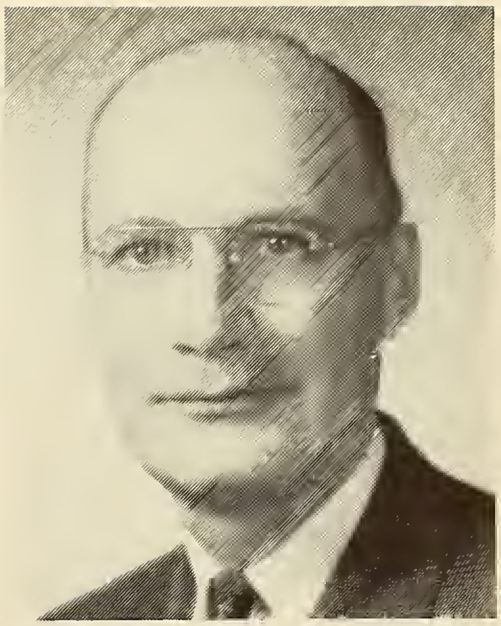

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INTRODUCTION

IT IS INDEED AN HONOR to take part in this centennial symposium on the Nutrition of Plants, Animals, and Man. I find it particularly gratifying to learn that the importance of fertilizer practices is recognized by including a discussion of them on this program.

Any factor believed to influence human nutrition is quite likely to excite public imagination. The role of fertilizers in nutrition is no exception. In fact, two opposing patterns of thought have developed: (1) food of inferior nutritional value is the product of impoverished soils and the use of fertilizers under these conditions will produce a better food; and (2) the use of inorganic chemical compounds as fertilizers will produce inferior foods. An examination of the facts, however, will show that generalizations of this kind are seldom true. It is the purpose of this paper to evaluate our present knowledge with respect to some of these matters and to suggest certain valid areas of research where agreement is such as to warrant further effort. In developing these lines of thought, I shall consider the effects of the mineral nutrition of plants on both the inorganic and organic components of the plant, the effects of fertilizer practices on the nutritional quality of plants as measured by animal assay, and the comparative effects of organic and inorganic sources of the nutrient elements on the nutritional quality of plants. At appropriate points, I shall introduce, by way of comparison to fertilizer effects, examples of the influence of environmental and soil factors on nutritional quality.

There is, of course, an extensive literature covering these areas of research. However, since many published conclusions are not based on carefully designed and controlled experiments, it is difficult to generalize from them concerning the effects of fertilizers on nutritional quality. My remarks are based on a study of this literature rather than reference to specific papers, and I shall illustrate my points mostly with data from our own laboratory.

THE EFFECT OF MINERAL SUPPLY ON THE CONCENTRATION OF MINERALS IN PLANTS

The effect of mineral supply in the nutrient medium on the concentration of minerals in the plant has been a subject of investigation longer than any to be considered in this paper. The results of many investigators have revealed a number of direct relationships as well as interrelationships that influence the absorption of mineral nutrients by the plant roots.

It has long been recognized that the quantity of any soluble or available mineral element in the nutrient medium does not necessarily bear a direct relation to what a plant will absorb. We know very little of the physiology or physical chemistry of the absorption processes. However, we do know that different ions behave differently. If our fertilizer programs designed to improve crop quality are to succeed, at least these gross differences in uptake should be recognized. The problem may be illustrated by the data in *figure 1.* It is clear that a vast difference has occurred in absorption of molybdenum and manganese from that of iron and copper. Boron and zinc appear to be intermediate. The results on both turnip leaves and tomato leaflets indicate that it will probably be difficult to introduce large quantities of copper or iron into plants as a result of applying these elements to the soil or other media. This has certainly been our experience in the field. Of course, the chelating compounds may help to solve

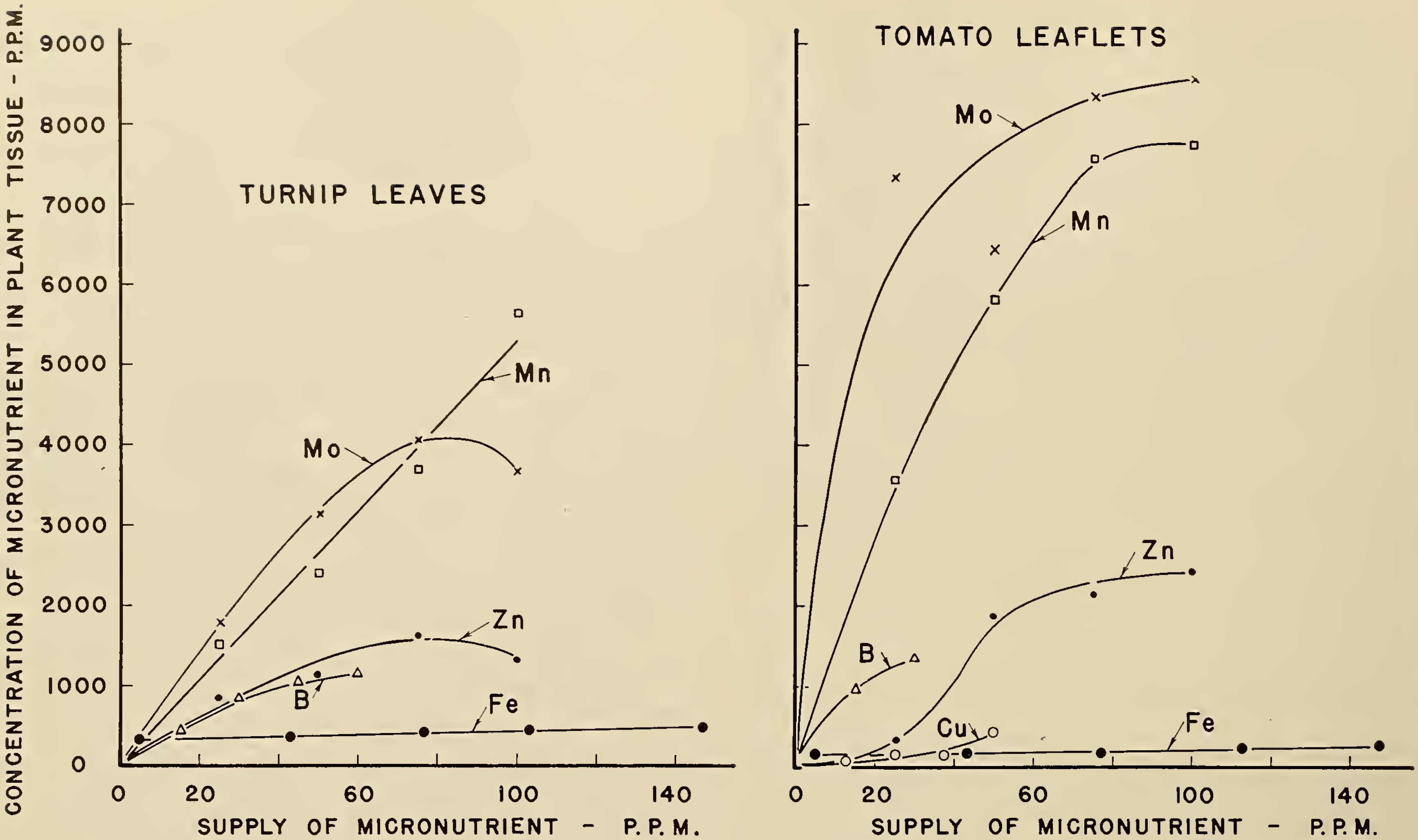

Fig. 1. Effect of supply, in toxic concentrations of micronutrient elements on their concentration in turnip leaves and tomato leaflets.

this problem. We are now investigating this situation in field studies carried on in cooperation with the New Hampshire Experiment Station. There is much to learn, here, of the effect of excessive absorption of a metal chelate on the metabolic processes in the plant. Possibly the plant has good and sufficient reasons of its own for not absorbing large quantities of copper or other ions.

The factors affecting the absorption of calcium are puzzling. Illustrated in *table 1* are some data showing that the addition of gypsum to the soil has, under the conditions of the experiment, had no effect at all on the concentration of calcium in the turnip plant (1).

TABLE 1—Selected data showing the effect of fertilization on the calcium content of turnip greens

Treatment	Location in Mississippi		
	Crystal Springs g.Ca/100g.	Poplar-ville g.Ca/100g.	Stoneville g.Ca/100g.
None	2.680	2.195	3.085
Gypsum	2.610	2.245	3.070
Nitrogen	1.740[a]	1.755[b]	2.400[c]

a. Sheets, *et al.* 1944.
b. Significantly lower at the 5% level.
c. Significantly lower at the 1% level. The test of significance is based on the entire study of 16 fertilizer treatments in 30 experiments.

A number of examples of this kind can be found in the literature. By contrast, Dr. Matrone has recently obtained some data at the North Carolina Experiment Station that show a marked increase in the calcium concentration in the plant resulting from additions of calcium carbonate to the soil. A knowledge of basic facts concerning the absorption of calcium by plants could open the door to highly important improvements in the nutritional quality of crops because of the importance of this element.

There are many conflicting reports in the literature concerning the effect of phosphate fertilizers on the phosphorus content of plants. It is difficult to evaluate them because important factors have not been controlled. The problem concerning phosphorus and many other fertilizer elements, particularly where yields are involved, may be illustrated by the diagram in *figure 2*. Consider the ideal curve AA′EG. In a very deficient soil, the application of a plant nutrient will result in an increase in yield or growth, but not increase in any important way the concentration of the element in the tissues of the plant. At some point, A′, as the supply of the element in the soil is increased both the growth of the plant and the concentration of the element in the tissues will increase. At another point, E, no further yield increases are obtained and further increments of the element are simply stored in increasing amounts in the plant tissue until the concentration becomes toxic to the plant. Theoretically, the points A′ and E can

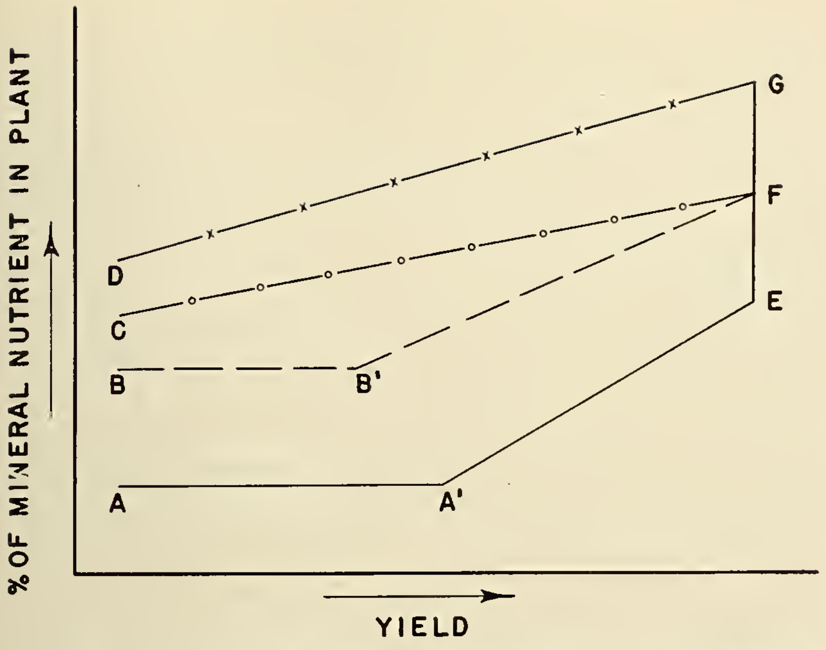

Fig. 2 The relationship between the yield and mineral content of plants.

be said to be associated with some other limiting factor in the soil. Practically, this view has its limitations. Our task in improving the nutritional quality of plants is to learn more of the basic facts here so that we can introduce into the plant through soil treatment adequate quantities of these elements important to animals and man. We have barely scratched the surface of this very important problem.

Among the commonly recognized pairs of nutrient ions that may modify the uptake and metabolism of each other are calcium and magnesium, calcium and boron, and iron and manganese. Others have been reported. Some of these interrelationships are now well supported, but others require further investigation. Thus, in some recent studies in cooperation with the New Hampshire Experiment Station we noted an apparent interrelationship between manganese and cobalt. A high application of cobalt to the soil was associated with a lower concentration of manganese in timothy. One might expect this from experience with iron and manganese, but the need for further work is certainly indicated.

Ionic interrelationships and their effect on uptake of ions by plants suggest an exciting field of research involving a whole new concept of fertilizer practices. For example, recently we have begun to look more closely at the concentrations in plants of mineral elements that are toxic to animals. As is well known to the nutritionist, current practice in the case of excesses involve supplying an element to the ration of the animal that will counteract the effect of the toxic element. Examples are arsenic for selenium and copper for molybdenum. Would it be possible by fertilizer practices to prevent the uptake of the noxious element by the plant?

The obvious manner of correcting the soil conditions in such instances would also be to supply a counter influence. Based on experience with known ionic interrelationships can we hope to discover an antagonistic factor to selenium, molybdenum, barium or vanadium absorption by plants? This is of real significance in the West where quite large areas of otherwise good grazing land could be utilized if satisfactory methods for retarding the absorption of these elements from the soil can be found. The addition of unusual substances may soon be recognized as orthodox fertilizer programs, particularly if we define our term to include any soil amendment that improves the growth and quality of our crop.

THE EFFECT OF MINERAL NUTRITION ON THE ORGANIC COMPOUNDS OF PLANTS

There are those who question the need for supplying directly to the soil the mineral nutrients required by the animal. The animal husbandman has already demonstrated the practicability of adding phosphorus, calcium, iodine, and cobalt to salt or the protein supplement. It has not been fully demonstrated, however, that in thus by-passing the plant some other nutrients are not being denied the animal. In considering this possibility I should like to discuss a few recent experiments that reveal some important reasons for a reconsideration of some of these views. First, however, it might be desirable to hold some general discussion of the effect of mineral nutrition on the organic compounds of plants as observed under controlled conditions.

Although the literature contains many references concerning the effect of fertilizers in increasing the ascorbic acid content of plants, carefully controlled experiments by Dr. Hamner and his associates at our laboratory, and by others since that time, have failed to support these observations. In our experiments wide variations in the supply of calcium, magnesium, potassium, nitrogen, sulfur, and phosphorus, resulting in large variation in yield of tomatoes and turnip greens, failed to modify their ascorbic acid content. Likewise, tomatoes grown in nutrient media deficient in each of the micronutrient elements, iron, manganese, copper, zinc, and molybdenum, did not vary materially in ascorbic acid content. Comprehensive field experiments with peas and tomatoes supported these findings. On the other hand, Dr. Hamner carried out controlled light experiments which indicated that a part of the variation observed in ascorbic acid content of a specific part of the plant was due to the quantity of light received by that part. Light appears to have a far greater effect on ascorbic acid in plants than does any variation in the nutrition of the plant.

The experience with carotene was similar to that with ascorbic acid with respect to both fertilization and light, except that any nutrient deficiency resulting in chlorosis of the plant also resulted in lower carotene content. Thus, it can be shown that correction of chlorosis by adding nitrogenous fertilizers to the soil will often result in a higher content of carotene in the

greener plant. Applications of boron to boron-deficient soils will also result in an increase in the chlorophyll and the carotene concentration in a plant like alfalfa.

Controlled experiments of similar nature with oats as the test crop have failed to show any relationship of mineral nutrition to the thiamine content of the grain. In general, we can conclude that any fertilizer practice resulting in optimum yields will probably result in an optimum vitamin content of the crop depending upon the variety and the set of environmental conditions prevailing at the time of growth.

More recently there has been a renewed interest in the nitrogenous constituents of plants and their relation to the supply of mineral nutrients. It has long been known that the protein content of plants varies with the location where grown. Wheat is the best known example. Until recently nearly all of our knowledge of nitrogenous constituents was based on a determination of the total nitrogen content. With the development of microbiological and chromatographic procedures, it became possible to examine more completely the effect of nitrogenous fertilizers and other nutrients on the amino acid composition of the proteins and on the free or soluble amino acids in the plant. Thus, it is now known that fertilization of corn with nitrogen will increase the concentration of the storage protein zein in the seed. However, this protein has a lower biological value for some animals than the other proteins in corn not so markedly affected by fertilization.

In our laboratory, Dr. Thompson has done some work on the effect of calcium, magnesium, and potassium on the concentration of proteins, protein composition, and the concentration of amino acids in turnip greens. A part of the results presented in *table 2* show no significant effect of treatment on the amino acid composition of the protein fraction. Hence, in harmony with our more recent understanding of the structures of proteins, it would appear that these components of plant tissue are fairly stable and characteristic for the specific tissue produced in the growing process.

If we examine the free amino acids, however, we do find some variation depending upon the nutrition of the plant. Some illustrative data are presented in *table 3*. If the supply of calcium in the nutrient solution is limited it appears to have no effect on the quantity of any amino acid including those shown here. In fact, we may go so far as to state that there is still no evidence that calcium affects nitrogen metabolism in plants.

TABLE 2—Effect of some mineral deficiencies of the composition of turnip leaf proteins

Amino acid	Relative amounts of each amino acid on a weight basis			
	Full nutrient	Low calcium	Low potassium	Low magnesium
Glutamic acid ..	2.55	2.85	3.23	2.62
Threonine*.....	1.0	1.0	1.0	1.0
Histidine.......	.22	.25	.16	.24

*Threonine concentration averaged 7.7 mg/g. dry weight of residue.

TABLE 3—Effect of some mineral deficiencies on the amount of nonprotein amino acids in turnip leaves

Amino acid	Full nutrient	Low calcium	Low potassium	Low magnesium
Glycine........	0.24	0.39	2.44	0.21
Threonine......	1.0	1.0	1.0	1.0
Glutamine.....	2.39	3.21	8.61	2.11
—amino butyric acid	2.48	4.22	2.51	.91

When Dr. Thompson limited the supply of magnesium in the nutrient solution one of the striking results was a lower gamma amino butyric acid content. No explanation for this can be offered at this time. He has also observed a high asparagine content in relation to magnesium deficiency. If potassium is limiting in the nutrient solution large increases in glycine and glutamine occur. Of course, these increases in free amino acids are simply indicative of their accumulation resulting from some block in the normal processes for forming proteins. This block, in turn, is probably the result of a limited supply of the particular mineral element under control.

Since the soluble or free amino acids comprise about twenty percent of the total nitrogenous components of plant tissue, the importance to animal nutrition of the variations noted here needs further clarification. The final test of such matters lies, of course, in feeding the plants or their parts to animals and noting such effects as weight change or the occurrence of pathological conditions. As an example of such a feeding test, I should like to discuss briefly an experiment carried out by Dr. Matrone in cooperation with the North Carolina Experiment Station. The purpose of the experiment was to test the effect of phosphate fertilization on the nutritional quality of soybean forage.

An area long out of cultivation and very deficient in available soil phosphorus was selected in 1945 for the production, over a number of years, of all of the crops necessary for the growth, reproduction and maintenance of sheep and rabbits. The crops grown included soybean forage. Yields of this crop were greatly increased as a result of phosphate fertilization and the phosphorus concentration in the forage, after the first year, was also increased.

When these crops were fed sheep, those receiving the forages from the phosphate fertilized plots gained the most weight. Supplementary feeding tests showed that the superiority of this forage was due only to the extra phosphorus it contained.

The rabbit, when used as a test animal for these forages, confirmed and extended the results obtained with sheep. The data from one such feeding trial are presented in *figure 3*. In this trial phosphorus and protein were eliminated as factors limiting growth by supplementing the soybean forage with $CaHPO_4$ and casein. Thus rabbits fed the unsupplemented forage grown without phosphate fertilization gained 460 grams in 8 weeks. The rabbits fed this forage with the addition of 8 grams of casein gained 535 grams. The rabbits fed the unsupplemented forage grown with phosphate fertilization gained about 500 grams in the 8-week period. Here, however, those fed this forage with the addition of 8 grams of casein gained 685 grams. These data demonstrated that there was a difference in nutritive value between these two hays beyond that caused by any difference in protein or phosphorus. That is, when these two factors were no longer limiting, one or more other unknown factors became limiting in the hay from the low phosphate treatment.

More recently Matrone has measured biologically some of the effects of liming the soil on the nutritional quality of lespedeza. Significantly better growth in rabbits was obtained with those animals fed the forage from the soils receiving the highest level of lime. Since the calcium concentration in the forage from the no-lime plots was high enough not to be a limiting factor, one can assume that liming had resulted in some other change than calcium concentration in the nutritional quality of the lespedeza. It should be noted that in this experiment not only an increase in the concentration of calcium resulted, but also of phosphorus. The implications in both animal and human nutrition are impressive.

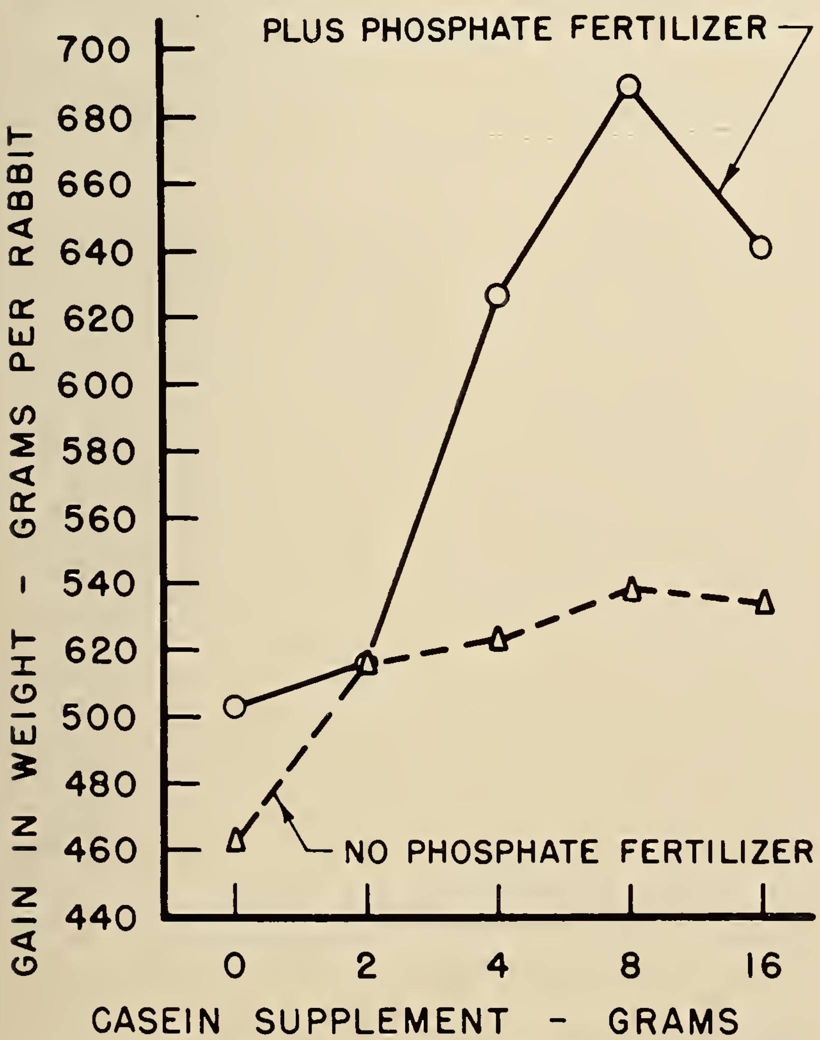

Fig. 3. Effect of casein supplement on the weight gains of rabbits fed hays from differentially fertilized plots.

TABLE 4—The effect of fertilization on the nutritional quality of turnip greens as measured by growth of rats

Location	Field replication	Weight gain in grams		
		No fertilizer	Plus fertilizer	Difference
E	1	95.4	91.7	− 3.7
E	2	98.7	109.2	+10.5
NC	1	96.7	107.7	+11.0
NC	2	108.0	111.0	+ 3.0

*Mean of four animals.

Other experiments, however, prevent our attempting any generalizations concerning the effect of fertilizers on nutritional quality of crops. In *table 4* there are presented some data on the growth of rats fed turnip greens grown in two locations in the South and with two levels of fertilization. This was a cooperative experiment carried out by Miss Gray of our laboratory and Dr. Speirs of the Georgia Experiment Station. The low level of fertilization was sufficient for minimum yields only, while the high level provided no maximum yields of this crop. In this experiment no significant differences due to fertilization were found. By way of contrast, when turnip greens from two other locations were incorporated into diets for rats, highly significant differences in growth of the animals were obtained. Fertilization was not a variable in this latter experiment.

The techniques for the biological assay of plant material to determine its nutritional quality are still in the developmental stage. Some of the most obvious problems include the selection of the test animal; the choice of the diet components that will permit sufficient stress to develop in the animal so as to emphasize differences in nutritional quality of plants from different environments and management practices; the preparation of plant material so that what is fed is representative of the conditions of growth; and the design of the experiments so that the experimental error includes plot variation and animal variation.

The development and execution of these tests require, therefore, the best we have to give. There is, indeed, a real need for more of this kind of research. Accumulated evidence is sufficient to warrant further effort in evaluating the effect of the nutrition of the plant on its overall nutritional value to animals and man. There are enough reports of differences in nutritional value of crops grown in different locations to make exciting the possibility of modifying through fertilization any soil so as to produce a crop of high nutritive value.

THE EFFECT OF ORGANIC MATTER ON THE NUTRITIONAL QUALITY OF CROPS

There is, of course, no reason for doubting the value of organic matter supplied as animal manures, composts, or otherwise to the soil. The evidence of its favorable effects on soil properties and crop production can be found throughout the literature. In recent years, however, a new interest concerning organic matter has arisen with respect to its effect on nutritional quality of crops. Many claims and counterclaims have been made, but few if any experiments have been recorded that permit a rigid interpretation of data. The experimental problem becomes one of growing crops without a trace of organic matter in the nutrient medium or without a trace of a mineral nutrient in the inorganic form in the nutrient medium. Practically, neither condition is feasible. Hence, the only course left to us is to try to determine what relative effect, if any, rather large quantities of organic sources of plant nutrients have as compared to principally inorganic sources of these nutrients.

This has actually been done by several investigators, sometimes with the intent of working with zero levels of each of these sources of nutrients, but without the discovery of any evidence favoring one practice over another. Dr. Brandt of our laboratory attempted this type of experiment some years ago. Every effort was made to maintain uniform conditions for the growth, harvesting, and analysis of crops grown with composts and with commercial fertilizers. Invariably, however, some difference arose to prevent valid conclusions. For example, in one study with carrots the results were complicated by large maturity differences due, probably, to the limited availability of the nutrients from the compost as compared to the more soluble forms found in the inorganic fertilizers. We were not concerned, however, because although the overall nutritional quality of the carrot was not determined, there is no basis on the results of this experiment to conclude that organic and inorganic sources of plant nutrients differ with respect to their effects on nutritional quality. If a difference had occurred, we would have found it difficult to interpret it.

For a more favorable effect of organic matter, we might refer to some of the findings of the Southern Cooperative Group. In an extensive and comprehensive experiment carried out some years ago they had the opportunity of comparing the iron content of their crop (turnip greens) with the organic matter content of their soils (2). They found a highly significant positive relationship between soil organic matter and the iron content. Some similar results were obtained by us in the analysis of potato tubers from the Long Island Vegetable Research Station. The results showed that the iron content was doubled where 40 tons of manure had been applied to the soil, although smaller applications appeared to have no effect. The treatments had no effect on the copper content of the tubers, although from many experiences with mucks, different results would not have surprised us.

Experiments designed to test biologically the effect of organic matter on nutritional quality have been reported. All of the experimental hazards noted heretofore are multiplied many fold in such investigations. In addition, there is the problem of producing under controlled conditions enough feed or food to carry on such an experiment for an adequate period. Because of this lack of adequate experimentation, we certainly are not in a position to draw final conclusions. We need more information of this kind for it is conceivable that the uptake of other mineral nutrients might be influenced as was iron in the experiments cited above. Nor do we know that nutritionally important organic compounds are not absorbed by the plant root under favorable conditions.

The controversy about organic versus inorganic sources of plant nutrients is one that has troubled many of us during recent years if for no other reason than a concern for the widespread publicity accorded many unsupported claims. There is still such a multitude of unanswered questions that one cannot and must not make positive statements concerning the issues. It is, however, possible on the basis of the relatively meager amount of direct evidence and the much larger sum of indirect knowledge, as well as certain sprinkling of logic, to throw doubt on the need for more and elaborate, time consuming and expensive experiments necessary to find all the answers at this time. Eventually they will be found in conjunction with other studies being actively pursued.

THE IMPORTANCE OF FERTILIZERS IN PRODUCING AN ADEQUATE FOOD SUPPLY

In this paper the importance of fertilizers in producing the quantities of food we need for our people and their food producing animals has not been stressed. To do so would involve us in the consideration of too many other problems. We must not ignore the fact, however, that the use of fertilizers permits us to exercise a choice of crops best suited to our nutritional needs no matter what the original soil condition may be.

Investigations of the relationship between fertilization and nutrition have the important function of indicating how greater quantities of better foods supplies can be provided for increasing world populations. During most of man's agrarian existence he has been able to grow his food on the best available soils. With rapidly increasing populations that day is passing and he must learn to use soils of a lower fertility level to produce crops of highest possible nutritive quality. Basic information about the effect of soil characteristics on the nutritional quality of food should be obtained now in order that problems, when they arise, can be

solved intelligently. Probably no critical situation exists at the present time, but this condition could change as the demand for more food forces its production on less desirable soils.

Our approach to this problem must be a sane one, not prompted by an emotionalism that will over-stimulate the public imagination with subsequent loss of its support. Mark Twain once said "One should be careful to get out of an experience only the wisdom that is in it and stop there, lest we be like the cat that sits down on the hot stove lid. She will never sit down on a hot stove lid again, and that is well. But, also, she will never sit down on a cold one any more."

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Effect of Fertilizer Practices on Nutritive Value of Feed for Four Successive Generations of Dairy Cows[1]

I. THE HEALTH, GROWTH, BREEDING EFFICIENCY, FEED INTAKE AND MILK YIELDS OF THE COWS

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PROCEDURE

THE FOUNDATION ANIMALS of the herd used on this project were of the Jersey and Holstein breeds. Seven pairs of half-sister Jersey bred-heifers were procured in 1945 from six different herds. These animals were divided into two groups such that each cow had a half-sister in the other group. One group received feeds from only the fertilized areas of the experimental farm; the other group from only the unfertilized areas. Two animals from each group were lost from the experiment before or during their first lactation period due to reasons other than the experimentation. Subsequently, six Holstein-half-sisters were added to the herd, three being added to each group. Heifer calves born into this herd were added to the group of which their dams were a part. An attempt was made to raise all heifers.

All feeds, with the exception of salt and such other supplements as were proven necessary, were produced on the fertilized and unfertilized areas, respectively. All supplements used were supplied to the animals of both groups. Oat hay was used the first year and mixtures of brome grass and timothy subsequent years, except partly oat hay in 1950. The mixture favored brome grass for 4 years and timothy for the last 4 years. The grain ration consisted of various proportions of ear corn, oats, wheat and soybeans, ground and mixed with one percent salt. The proportions depended on the amounts of the various grains that were produced and were maintained the same for both groups. Crop failure in any case necessitated the discard of the produce from that crop in the other category.

The herd was maintained on the hay-grain, dry-feed regime until June, 1954 when silage was introduced into the ration. Hay was fed in amounts readily consumed by the animals with little or no refusal. The grain mixture was fed in amounts that varied with the level of milk production and with the amount of grain available for a given crop year. Each calf was fed colostrum from its dam for 2 days and then was fed milk from cows in the calf's respective group for approximately 6 months. The calves were given access to the appropriate hay and grain mixture at an early age. The calves were fed hay according to appetite and grain was fed likewise up to 4 to 6 pounds per head daily depending on amounts available. All animals were fed twice daily.

The animals were allowed to exercise regularly in a dry lot. During the first 3 years the lot was bare soil but since that time the exercise lot has been concrete pavement.

The health of the animals has been measured by observation and blood analyses. Appearance of symptoms of deficiency of a known nutrient in both groups was followed by supplementation of that nutrient for both groups as long as it was deemed necessary. Veterinary attention was given wherever necessary excluding mineral or vitamin therapy. Blood samples were taken at monthly intervals on the herd and on the dam and calf immediately after calving and 72 hours later.

RESULTS AND DISCUSSION

Feed Composition

The chemical composition of the grain rations and timothy hay was summarized for 8 and 4 years,

[1]Supported in part by a grant from the National Dairy Council on behalf of the American Dairy Association.
[2]Present address: Office of Experiment Stations, U.S.D.A., Washington 25, D.C.
[3]Deceased.

TABLE 1—Average composition of feeds (on dry matter basis)

	Timothy hay		Grain mixture	
	Fert.	Unfert.	Fert.	Unfert.
No. years	4	4	8	8
No. samples	13	13	25	25
Crude protein (%)	6.5	5.8	16.3	16.6
Crude fiber (%)	35	36	8	8
Ether extract (%)	2.2	2.1	6.6	6.6
Ash (%)	4.1	‡ 3.1	4.3	4.1
Carotene (ppm)	11.1	5.9	2.7	2.9
Calcium (%)	0.22	‡ 0.14	*0.18	*0.18
Phosphorus (%)	0.18	‡ 0.10	0.46	† 0.41
Magnesium (%)	0.11	0.10	0.21	† 0.22
Potassium (%)	1.43	‡ 0.80	0.71	0.72
Manganese (ppm)	64	‡ 84	45	45
Copper (ppm)	13	† 8	13	15
Iron (ppm)	101	105	85	87
Cobalt (ppm)	0.08	0.08	0.10	0.09

*Supplemental calcium given during 3 years. Five-year unsupplemented average—fertilized 0.07%, unfertilized 0.07%.
†Significant at the 5% level of probability.
‡Significant at the 1% level of probability.

respectively. Mean concentrations were obtained for constituents of the fertilized and unfertilized feeds and are shown in *table 1*. Timothy hay from the fertilized areas showed highly significantly more ash, calcium, phosphorus and potassium. There was a significant difference in the copper concentration in the hays. On the other hand, the manganese content of the timothy hay from the more acid, unfertilized soil was highly significantly greater. The phosphorus and magnesium contents of the grain mixtures varied significantly.

Reproduction

One hundred and seven calvings have occurred on this project. Twelve of these were to the original Jersey cows but the resulting calves were discarded since they were not conceived on the project. Of the remaining 95 calves born, 52 were heifers. Nineteen of the heifers were dead at birth or died in calfhood. The groups were approximately the same in this respect, seven of 21 dying in the fertilized group and 12 of 31 in the unfertilized group.

The calf birth weights were summarized by breed and sex and are presented in *table 2*. A significant difference was found between the mean birth weights of fertilized and unfertilized Jersey males. This difference was 11 pounds in favor of the unfertilized group. The Jersey female calf birth weight varied in the same direction but not significantly.

TABLE 2—Calf birth weights (means)

	Jersey		Holstein	
	Male	Female	Male	Female
	lb.	*lb.*	*lb.*	*lb.*
Fertilized	42 (9)	43 (12)	97 (9)	91 (8)
Unfertilized	53 (4)	47 (11)	97 (11)	88 (13)
Difference	11*	4	0	3

*Significant at the 5% level of probability.
( ) Number of observations.

The breeding efficiency was summarized for the two groups (*table 3*). Even though there was an actual difference of one service per conception the difference was not statistically significant. The individual variations from conception to conception and from cow to cow were greater than between groups. No effect of crop year was evident. The poor breeding efficiency has not been accounted for as yet but the possibility exists that the continual dry-feed, barn regime may have been somewhat responsible.

Heifer growth was summarized by breed, group and generation. These data are presented in *figures 1 to 4*. No real differences are indicated.

Health

The blood analyses for lactating cows were summarized by group and by generation. Scrutiny of these averages (*table 4*) revealed essentially no difference between groups for hemoglobin, red blood cell volume, calcium, inorganic phosphorus, magnesium and vitamin C contents. Some variation occurred in carotene and vitamin A contents both between groups and among animals within groups so it is doubtful if any real differences exists between these values for the two groups.

It was planned that, where need was demonstrated in both groups, adequate nutritional supplement would be made. Many of the cases of calf mortality and of calves that were weak but lived had low vitamin A levels in the blood. Consequently it was regular practice during the first 2 years of the experiment to supplement calves immediately after birth with shark liver oil. During the sixth year of the experiment it became increasingly evident that a large proportion of the calves were being born weak or dead and the pregnacies were terminating early, at eight months or more. At the same time inspection of the results of blood analyses for the cows during that time indicated low vitamin A concentrations,

TABLE 3—Breeding efficiency (by year of calving)

Year	Fertilized		Unfertilized	
	Conceptions	Services per conception	Conceptions	Services per conception
1947	6	1.3	6	1.8
1948	6	4.0	5	1.4
1949	5	1.6	8	2.5
1950	4	3.7	6	2.2
1951	3	2.3	5	1.6
1952	6	3.8	9	2.2
1953	6	4.5	6	2.3
1954	6	3.0	8	2.2
Summary	42	3.1	53	2.1

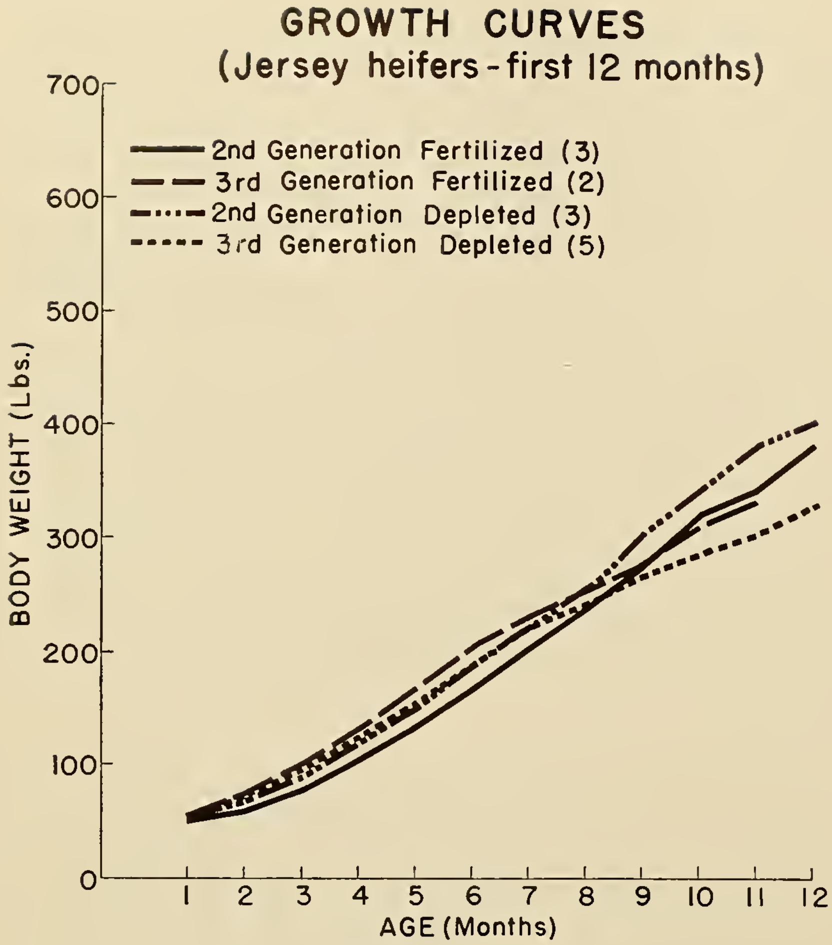


Figure 1.

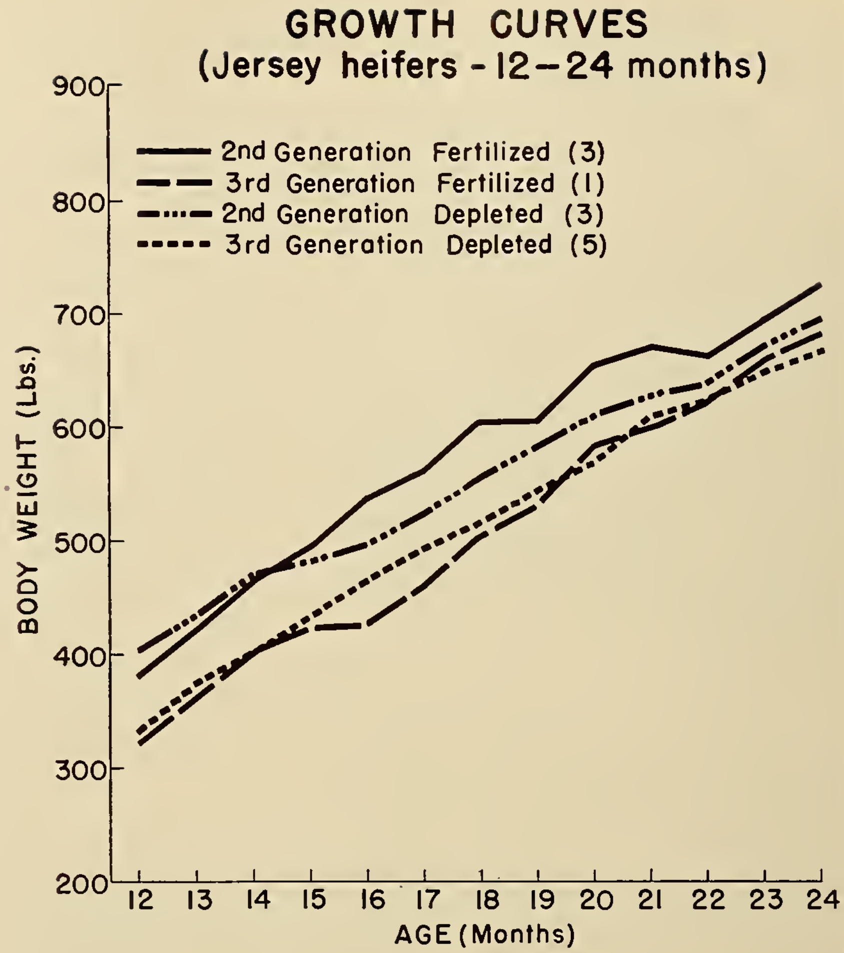


Figure 2.

even as little as zero. The two groups had the similar pictures with regard to reproduction and blood viatmin A concentrations. At this time supplementation of each animal in the herd weekly and each calf at birth with 100,000 I.U. of vitamin A in the form of Myva-Dry Powder by capsule was started. This supplement was continued for three and one-half years. The difficulty with regard to the weak and dead calves was alleviated but sporadic periods of difficult settling have persisted.

Exceptionally poor appetite by many of the cows and complete refusal of feed by two cows late in 1950 was alleviated by cobalt supplementation. Analysis

TABLE 4—Blood picture—Lactating cows

Group	Fertilized		Unfertilized		
Generation	1st	2nd	1st	2nd	3rd
Determination (no.)	185	140	211	191	41
Whole blood					
Hemoglobin (gm.%)	11.4	11.1	11.7	11.0	11.0
Volume RBC (%)	27.9	28.6	28.0	28.1	29.0
Plasma					
Calcium (mg.%)	10.6	9.8	10.7	10.1	9.6
Inorganic Phosphorus (mg.%)	5.4	5.9	5.3	5.7	6.3
Magnesium (mg.%)	2.0	2.8	2.2	2.7	2.9
Vitamin C (mg.%)	0.44	0.47	0.45	0.45	0.44
Carotene (ug.%)	161	224	220	127	138
Vitamin A (ug.%)	10.8	16.3	11.5	12.9	13.2

of the feeds indicated that the cobalt intake of the cows of both groups was considerably below levels considered adequate. Cobaltized salt was included in the grain ration until the 1951 crop was harvested. Apparent cobalt deficiency was noted again with the use of the 1953 crops, especially in the fertilized group. Cobalt supplementation for both groups was started March 1, 1954 and continued until the new crop came in.

Analyses of the 1951 crops indicated dangerously low calcium intakes, especially in recognizing marginal intake during previous years. Calcium carbonate supplementation in the amount of 1 percent of the grain ration was inaugurated December, 1951 to preclude the possibility of deficiency of this element. This supplement was discontinued July, 1954.

Urea supplementation during May and June of 1954 was occasioned by the unusually small crop of fertilized soybeans of the previous season, 54 bushels. Urea was used in the grain mixture in the amount of 2 percent.

In June, 1950 several cows with no regard to group reacted to the tuberculin test. Considerable interest was manifested by the veterinarians since the herd was isolated and had previously been free of the disease. One reactor from each group was autopsied with negative findings. Speculations as to the cause of the difficulty included undue sensitization to the tuberculin serum, and the possibility of Johne's disease. The situation cleared spontaneously and the herd has passed

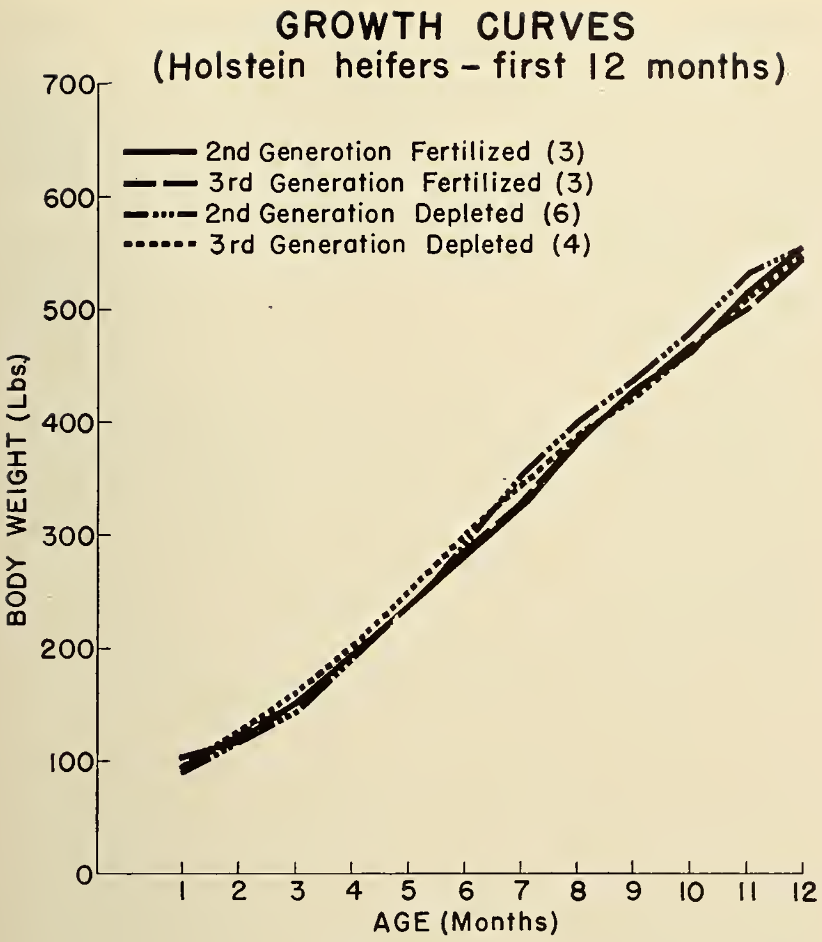


Figure 3.

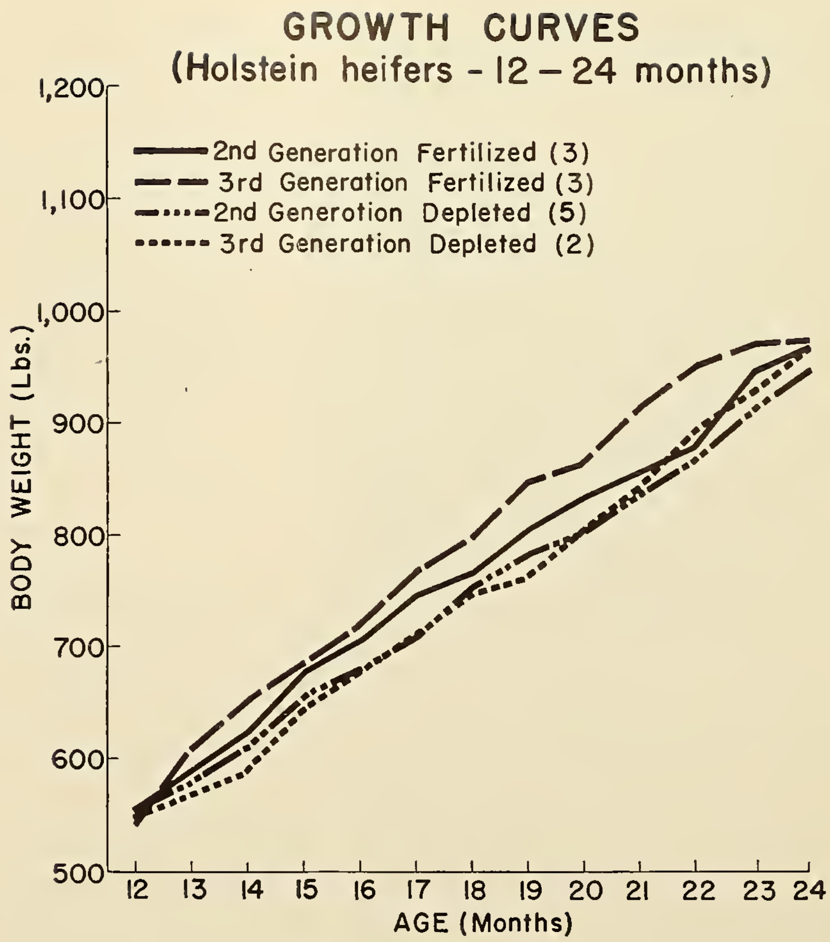


Figure 4.

several clean tests since then. No explanation was found.

Production

Eighty-one lacations by 35 cows were available for analysis. Only lactations of 250 days or more duration were included in these comparisons. Analysis of the lactation data for variance indicated highly significant variation among cows within groups as would be expected. The difference between groups, 6,353 lbs. 4 percent FCM for fertilized and 6,912 lbs. for unfertilized or a difference of 559 lbs. 4 percent FCM, approached significance.

The possibility of year-to-year variations being a factor had to be considered. Consequently the data for total digestible nutrient (TDN) intake and 4 percent fat corrected milk (4 percent FCM) were assembled for inspection according to years (*figure 5*). Mean values were determined. In seven of the nine years the mean yield of 4 percent FCM for the unfertilized group was larger than that of the fertilized group. One of the exceptions embraced only one lactation for the fertilized group.

Inspection of the mean TDN values for the same periods revealed a nearly identical trend. This indicated that variation in TDN intake probably was associated with the variation in 4 percent FCM production. However, the fact that both Holstein and Jersey cows were represented was a possible confounding factor.

When the intake and production data were summarized by breed the picture became more confusing (*table 5*). The TDN intake and 4 percent FCM production for the Holstein cows were greater in the fertilized group but not significantly so. On the other hand the Jersey cows in the unfertilized group consumed significantly more TDN and produced significantly more milk than the Jersey cows in the fertilized group.

Analysis of the Jersey feed intake and milk production data for covariance revealed that the feed intake variation was intimately associated with the variation in 4 percent FCM. The mean difference in 4 percent FCM milk production for Jersey cows when adjusted to equal TDN intake became an insignificant 269 lbs.

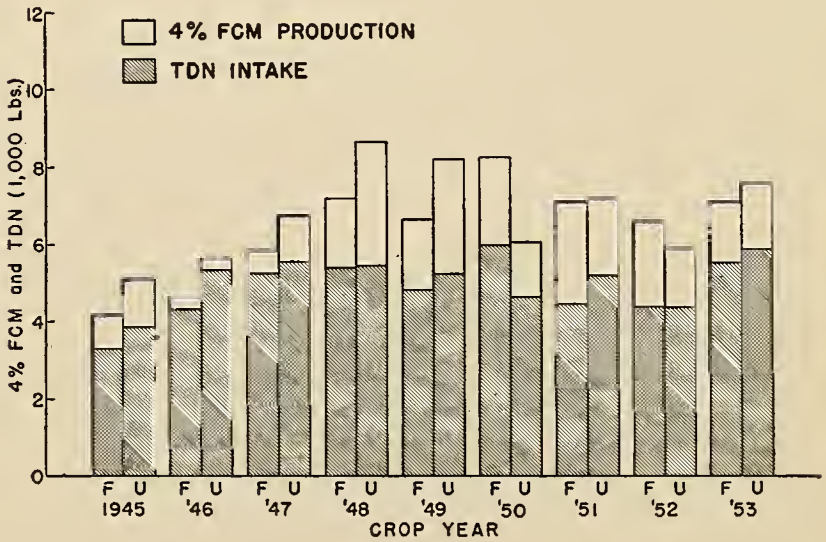


Figure 5.

TABLE 5—Summary of nutrient intake and milk production (means)

Group	Jersey		Holstein	
	TDN	4% FCM	TDN	4% FCM
	lb.	*lb.*	*lb.*	*lb.*
Fertilized.........	(21) 4,093	5,333	(13) 5,903	8,001
Unfertilized.......	(25) 4,620	6,129	(22) 5,544	7,802
Difference........	527*	796*	359	199

*Significant at the 5% level of probability.
( ) Number of observations.

These results are extremely interesting when the history of the roughage is understood. The first 3 years' hay was rather coarse on the fertilized land and fine on the unfertilized area. The cows greatly preferred the latter as was indicated in palatability trials. In an attempt to equalize this condition the plan was adopted to cut the fertilized hay earlier in subsequent years, resulting in a less mature crop. More recently the unfertilized area has received increased nitrogen fertilization and the hay crop has been less fine but it was cut later than that on the fertilized area. These practices favored the fertilized hay with regard to nutritive value if evaluated at present-day standards.

After the cows had completed three or more lactations in their respective groups they were fed a ration consisting of the so-called "Kellogg" hay and largely fertilized grains for one or more lactations. The Kellogg hay was produced on soil of the same type but which had a history of good management. The hay consisted of various proportions of alfalfa and smooth brome grass. Comparison of the average analyses of Kellogg and Timothy hays in *table 6* indicates some difference in protein content as well as in mineral constituents probably largely due to species difference.

TABLE 6—Average composition of Kellogg and Timothy Hays (on dry matter basis)

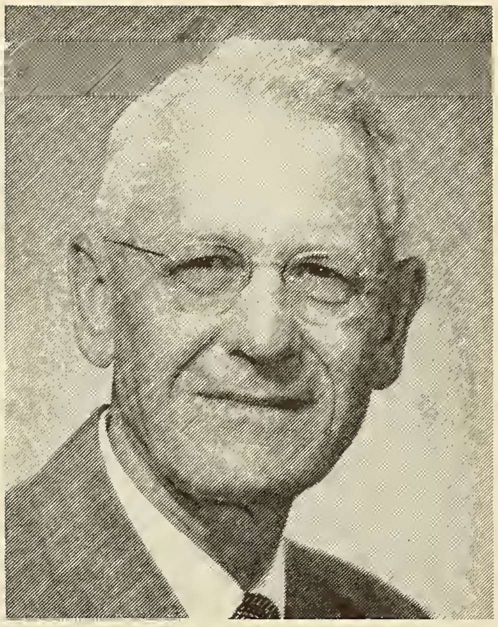
	Kellogg	Timothy
Number years..................	4	4
Number samples................	12	26
Crude protein (%)..............	11.3	6.0
Crude fiber (%)................	37	35
Ether extract (%)..............	1.7	2.1
Iron (ppm).....................	132	103
Cobalt (ppm)...................	0.10	0.09
Carotene (ppm).................	16.1	8.5
Ash (%)........................	5.1	3.6
Calcium (%)....................	0.52	0.18
Phosphorus (%).................	0.24	0.14
Magnesium (%)..................	0.19	0.11
Potassium (%)..................	0.24	0.14
Manganese (ppm)................	68	74
Copper (ppm)...................	10	10

TABLE 7—Results with Kellogg hay (9 cows)

	TDN	4% FCM
	lb.	*lb.*
Previous lactation................	5,496	8,226
Kellogg lactation.................	6,754	9,882
Difference......................	1,258	1,656

Nine cows, eight from the unfertilized group and one from the fertilized group, completed one or more lactations on the Kellogg ration. Comparison of their TDN intake and 4 percent FCM production with those of their previous lactation (*table 7*) showed increased feed intake with concurrent but not an efficient increased milk production.

Effect of Fertilizer Practices on Nutritive Value of Feed for Four Successive Generations of Dairy Cows



PROFESSOR C. W. DUNCAN of the Department of Agricultural Chemistry at Michigan State College. Mr. Duncan, a member of the staff at MSC since 1929, is the author of more than 90 articles, pamphlets, and books in the field of dairy science.

II. COMPOSITION OF MILK PRODUCED FROM FEEDS GROWN ON FERTILIZED, UNFERTILIZED SOIL[1,2]

By C. W. Duncan
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IT WAS SHOWN YESTERDAY, in the report on the composition of the plant species grown on the fertilized and unfertilized portions of the experimental farm that only minor differences occurred under the conditions of this experiment except in the composition of the timothy hay. Matrone, *et al.,* (7) in discussing the nutritive value of crops stated ". . . the content of a nutrient in the plant is not a measure of its availability to the animal. The final proof of nutritive value, therefore, is still provided only by some response of the animal."

For the past 10 years the nutritive value of the feeds produced on the experimental farm have been determined by maintaining two herds of cows continuously and solely on the feeds grown on either the fertilized or unfertilized soil and by keeping accurate records on the health, milk production, and reproduction of each cow. The amount of milk produced by every cow in each group has been recorded and various constituents have been determined routinely in the milk. These values have been compared with those recorded in the literature for normal cow's milk. The importance of this work lies in the fact that definite information has been obtained on the influence of soil fertility on the composition of milk and on the nutritive value of some crops used for both animal and human foods.

The voluminous literature concerning the chemical composition of milk does not permit a comprehensive review, but certain general observations should be made at this time. Over 30 years ago, Cary and Meigs (2) found that the yield of milk was reduced markedly when the amount of protein in a cow's ration was abruptly reduced or when the kind of protein in the ration was replaced with a different type of protein. The change in the amount or kind of dietary protein only caused a small and variable alteration in the composition of milk. Eckles, Becker and Palmer (3) and Huffman *et al.,* (4) and others found that a deficiency of phosphorus in the ration of cows decreased the milk yield but did not appreciably alter the phosphorus content of the milk. It has also been shown that the feeding of more than the required amounts of calcium or phosphorus to cows on an already adequate ration did not increase the amount of these elements in the milk. Wurster (8) reported that a high calcium soil increased the calcium content of forage but the calcium content of the milk could not be increased by feeding this forage to cows.

It has been established, however, the chief constituents in milk vary to a considerable degree due to breed differences, season of the year, stage of lactation, environmental temperature, inanition, individuality of cows, and diseases of the udder. All of these factors have been shown to cause variations in the composition of milk, but no conclusive evidence has been found to indicate that normal cattle feeds specifically alter the composition of milk.

The object of this part of the long-time experiment has been to determine whether the continuous feeding of the same plant species grown on fertilized and depleted soil of the same type would cause major alterations in the composition of milk.

EXPERIMENTAL

Three-day composite samples of milk have been collected each month from every cow in lactation since

[1]Supported in part by a grant from the National Dairy Council on behalf of the American Dairy Association. The amino acid and B-vitamin portion of the work was financed by the American Dairy Association of Michigan.
[2]The Nutrition Committee takes this opportunity to acknowledge the services rendered by R. Merwin Grimes, G. C. Gerritsen, and Alice J. Rykala in making all of the milk, blood, and colostrum analyses.

the experiment started in 1945. These samples have been analyzed regularly for the following constituents: total solids, butterfat, total nitrogen, lactose, ash, calcium, phosphorus, magnesium, manganese, carotene, and vitamin A. In some cases, the essential amino acids in the milk proteins and some of the B-vitamins have also been determined. In addition to the routine analysis of milk, colostrum was collected from each cow as soon after freshening as possible and the same constituents were determined as in milk, plus iron, copper, cobalt and potassium. The methods of analysis recommended by the Association of Official Agricultural Chemists (1) were used whenever they were applicable. The amino acids and B-vitamins were determined by standard microbiological methods.

All of the heifer calves from the first generation cows were saved. These calves received only the feeds grown on either the fertilized or unfertilized soils and were added to their respective milking herds after they had had their first calf. The heifer calves of the second generation cows also were saved and added to their respective milking herds. It is important to point out that none of these cows or their calves have ever had access to any feed except that grown on the fertilized or unfertilized soil nor have they ever been on pasture or had access to soil.

The data presented in this paper are summarized by 305-day lactation periods. These data disregard differences in breed; however, approximately an equal number of lactations were obtained from the Jersey and Holstein cows in each group. It should be mentioned, however, that the milk from individual cows varied in composition between wide limits. The composition of the milk of individual cows also changed with the progress of lactation; some constituents increased and others decreased as lactation advanced. These findings are recognized as normal.

TABLE 1—Average composition of milk produced by the 1st and 2nd generation cows during the first lactation period

		Fertilized		Unfertilized	
		1st	2nd	1st	2nd
No. of cows		4	7	6	8
No. of samples		32	70	59	80
Total solids	%	12.7	13.7	12.5	13.3
Fat	%	4.0	4.3	4.0	4.1
Protein	%	3.4	3.5	3.4	3.5
Lactose	%	4.7	4.9	4.6	4.8
Carotene	γ%	13.4	13.5	15.1	11.8
Vitamin A	γ%	4.5	7.4	5.0	6.3
Ash	%	0.77	0.76	0.77	0.76
Calcium	%	0.133	0.125	0.130	0.120
Phosphorus	%	0.098	0.110	0.098	0.107
Magnesium	%	0.010	0.013	0.010	0.013
Manganese	γ%	6.5	5.9	7.4	7.0

RESULTS AND DISCUSSION

Comparisons of the average composition of the milk produced by these two groups of cows are shown in *tables 1 to 4*, inclusive. *Table 1* shows the composition of the milk produced by the first and second generation cows during their first lactation period. These data indicate that four cows receiving the fertilized feeds produced seven offspring and that six cows receiving the unfertilized feeds produced eight offspring that were included in the milking herd. These values are the average of all the monthly values for each 305-day lactation period and for the number of cows indicated at the table heading. Inspection of columns 1 and 3 shows no differences in the composition of milk of the first generation cows due to feeds grown on either fertilized or unfertilized soils. An inspection of columns 2 and 4 also indicate no differences in the milk constituents of the second generation cows due to the feeds. Another interesting observation concerning the table shows that the second generation cows secreted as much or more of the various constituents in their milk as their dams. The concentration of manganese in the milk of the cows receiving the unfertilized feeds is slightly higher than found in the milk of the cows receiving the fertilized feeds. This was probably due to the fact that the unfertilized feeds, particularly the roughages, contained more manganese.

Table 2 shows the amount of total solids, fat and protein that was found in the milk of the same cows (*table 1*) on successive lactation periods. It is of interest to

TABLE 2—Comparison of the milk constituents produced by the 1st and 2nd generation cows during their first 3 lactation periods

		Lact. no.	Fertilized		Unfertilized	
			1st	2nd	1st	2nd
Total Solids	%	1	12.7	13.7	12.5	13.3
		2	13.3	13.3	12.6	13.3
		3	13.4	14.1	13.0	13.8
Fat	%	1	4.0	4.3	4.0	4.1
		2	4.2	4.1	3.8	4.1
		3	4.3	4.7	4.1	4.3
Protein	%	1	3.4	3.5	3.4	3.5
		2	3.5	3.5	3.5	3.7
		3	3.5	3.9	3.4	3.7
Ash	%	1	0.77	0.76	0.77	0.76
		2	0.78	0.74	0.79	0.76
		3	0.79	0.77	0.79	0.76
Calcium	%	1	0.133	0.125	0.130	0.120
		2	0.138	0.125	0.124	0.121
		3	0.132	0.139	0.129	0.128
Phosphorus	%	1	0.098	0.110	0.098	0.107
		2	0.097	0.104	0.099	0.106
		3	0.098	0.106	0.100	0.105

TABLE 3—Average composition of milk produced by the 1st, 2nd and 3rd generation cows during their first lactation periods

(Unfertilized feeds)			
No. of cows.........	3	3	5
No. of samples......	29	26	41
	1st	2nd	3rd
Total solids %......	12.8	13.8	13.1
Fat %......	4.1	4.4	3.9
Protein %......	3.4	3.7	3.5
Lactose %......	4.6	4.9	4.9
Ash %......	0.76	0.77	0.76
Calcium %......	0.135	0.129	0.127
Phosphorus %......	0.098	0.106	0.105
Magnesium %......	0.010	0.013	0.015

note that the cows in both groups had a tendency to secrete more of these three constituents in the milk with each succeeding lactation. This observation applies to both the first and second generation cows. When columns 1 and 3 and 2 and 4 are compared, there is nothing to indicate that feeding crops that are grown on fertilized soil are superior to the same crops grown on unfertilized soil. In nearly all cases, the second generation cows produced milk that was equal to or better than their dams produced, in so far as these constituents were concerned. The table also shows the ash, calcium and phosphorus content of the milk produced by these two groups of cows during the first three lactation periods. Again there is nothing to indicate that the long-continued consumption of feeds grown on either fertilized or unfertilized soils markedly influenced the mineral composition of the milk. These constituents did not vary markedly from one lactation to another or from one generation to another.

The average composition of milk produced by three first generation cows, their three daughters and five granddaughters during the first lactation period on the unfertilized feeds are shown in *table 3*. None of the first generation cows receiving the fertilized feeds have had granddaughters that have as yet completed their first lactation period. These average values show that the constituents in the milk of the second generation cows had a tendency to be higher than was found in the milk of their dams. The average values for the constituents in the milk of the third generation cows had a slight tendency to be lower than was found for the milk of their dams (second generation cows), but the values were equal to or better than those found in the milk of the first generation cows. The third generation cows received the unfertilized timothy hay as their only source of roughage. Under the conditions of this experiment, the data indicate that the feeds grown on the unfertilized soil and fed to three generations of cows have not had any deleterious effects on the composition

TABLE 4—Average composition of milk produced by all cows receiving the feeds grown on the fertilized and depleted soil

No. of samples......	325	440	99	......
No. of lactations.....	37	46	10	......
	F.	U.	Kellogg	N.R.C.
Total solids %	13.5	13.2	13.1	12.7
Fat %	4.3	4.1	4.0	3.7
Solids-not-fat %	9.2	9.1	9.1	9.0
Protein %	3.6	3.6	3.7	3.3
Lactose %	4.8	4.8	4.7	4.8
Carotene γ%	14.5	13.5	17.8	38.0
Vitamin A γ%	6.3	5.5	9.2	34.0
Ash %	0.77	0.77	0.78	0.72
Calcium %	0.131	0.126	0.121	0.125
Phosphorus %	0.103	0.103	0.102	0.096
Magnesium %	0.012	0.012	0.014	0.012
Manganese γ%	6.4	7.7	5.3	2.0

of the milk produced by the cows, so far as these constituents are concerned.

The average composition of the milk produced by all of the cows that have completed a lactation period on the fertilized or unfertilized feeds from the start of the experiment are summarized in *table 4*. Some data were omitted from both groups because some of the cows failed to complete the lactation period. Inspection of these average values fails to reveal any marked differences in the composition of the milk that can be attributed to feeds grown on soil badly depleted in mineral content. When these values are compared with those reported in the National Research Council Publication 254, all of the experimental values are equal to or better than those recorded for mature cow's milk, except of course, for carotene and vitamin A. It should be emphasized again that none of the experimental cows have ever been on pasture, have been fed silage, or have been allowd to exercise on soil. Their rations have been restricted so far as pasture or green feed have been concerned. The third column represents a supplemental experiment that was started after the experimental cows had completed three or more lactations on the fertilized or unfertilized feeds. They were changed to a ration of legume hay and a grain mixture to determine whether they had the capacity to produce more milk on a better ration and also to see if the composition of the milk would be altered. The data indicated in column 3 are the results obtained from 10 lactation periods. No marked difference is noted in the composition of milk, except for an increase in the carotene and vitamin A content of the milk, which can be accounted for by the higher carotene content of the legume hay.

Table 5 shows the essential amino acid composition of the milk proteins produced by the cows receiving the feeds grown on the fertilized and unfertilized soil. Each 60-day sample of milk was a composite of the milk produced on the 59th, 60th and 61st day of

TABLE 5—Essential amino acid composition of milk (Values in grams per 100 gm. of protein)

	60-day milk		Terminal		Evap.	N. R. C.
No. of samples ...	25	34	16	26	18	....
	F.	U.	F.	U.		
Arginine.........	4.0	4.1	4.0	4.0	3.5	3.8
Histidine.........	2.8	2.7	2.7	2.7	2.4	2.4
Isoleucine........	6.5	6.2	6.4	6.5	6.4	6.4
Leucine..........	8.9	8.7	8.6	9.0	9.4	10.8
Lysine...........	8.0	8.1	7.6	8.0	7.1	7.8
Methionine.......	2.3	2.4	2.4	2.4	2.3	2.6
Phenylalanine....	4.6	4.5	4.7	4.7	4.5	5.2
Threonine........	4.6	4.4	5.1	5.0	4.7	4.6
Tryptophane......	1.5	1.5	1.4	1.4	1.3	1.5
Valine...........	7.3	7.1	7.2	7.2	6.6	6.9
Protein (%)......	3.2	3.1	4.6	4.6	3.7	3.3

lactation. This stage of lactation was arbitrarily chosen to obtain representative samples of milk produced at the same stage of lactation of each cow. The samples were used in rat feeding experiments to obtain information on the nutritive value of the milk. If the distribution of the amino acids in the milk proteins were altered by the ingestion of feeds grown on the unfertilized soil, then the nutritive value of the milk would be limited. The terminal samples represent the last milk produced before the cow was dried off. The amino acid content of the evaporated milk was determined in connection with the rat feeding work and also for comparative purpose with the experimental milks. The data obtained from the 60-day samples indicate that the experimental milks were comparable in the number of grams of each amino acid per 100 gm. of milk protein. They also show satisfactory agreement with the values recorded in Publication 254 of the National Research Council. The total number of amino acid values on record are relatively small in comparison to the large number of values reported for the major constituents, such as protein, fat, minerals, etc. In some respect our experimental values are more in agreement with those reported by Kuiken and Pearson (5) for Holstein and Jersey milk. In general, the amino acid content of all of the milks showed good agreement. The data indicate that the feeds grown on the depleted soil were not capable of changing the amino acid distribution of milk proteins.

Whenever possible, the essential amino acid content of "first" colostrum was determined to see what differences, if any, the feeds grown on the unfertilized soil might have on the amino acid content of the mixed colostrum proteins. The results are presented in *table 6*. The data show such close agreement that no difference can be detected in the amino acid composition of the colostrum proteins produced by the experimental cows that can be attributed to feeds grown on fertilized or unfertilized soils. The last column is included for comparative purposes to show the average results

TABLE 6—Essential amino acid content of "first" colostrum (Values in grams per 100 gm. of protein)

No. of samples......	23	36	12
	F.	U.	K. & P.
Arginine............	4.3	4.4	4.2
Histidine...........	2.4	2.4	2.4
Isoleucine..........	5.2	5.1	4.7
Leucine............	8.3	8.3	9.1
Lysine.............	7.2	7.4	8.1
Methionine.........	1.9	1.9	1.9
Phenylalanine.......	4.5	4.3	4.5
Threonine..........	7.2	7.4	7.0
Tryptophane........	1.7	1.7	....
Valine.............	8.0	8.1	7.7
Protein (%)........	14.8	15.5	15.0

obtained by Kuiken and Pearson (5) for seven Holstein and five Jersey cows.

Table 7 shows the concentration of some of the vitamins present in "first" colostrum, 60-day milk, and terminal milk. The values taken from Publication 254 of the National Research Council for mature cow's milk are included for comparative purposes. Inspection of these data indicate that the riboflavin content of colostrum and 60-day was slightly higher when the cows received the fertilized feeds. The values obtained for 60-day milk, however, show fair agreement with those recorded in the National Research Council bulletin for mature cow's milk.

TABLE 7—Vitamin content of "first" colostrum and milk (Values in gammas per 100 ml.)

	Colostrum		60-day milk		N. R. C.	Terminal	
No. of samples	21	37	21	29	...	13	22
	F.	U.	F.	U.		F.	U.
Riboflavin....	595	511	140	119	157	142	165
Niacin.......	104	111	69	73	85	72	75
Pantothenic acid........	424	402	449	439	350	434	399
Vitamin A....	114	131	6.3	5.6	34	11.6	12.6
Carotene.....	86	66	12.8	11.1	38	16.4	16.6

SUMMARY

A long-time experiment has been conducted to determine whether the composition of milk could be altered by maintaining several generations of cows solely on the same plant species grown on fertilized and badly depleted soil of the same type.

Under the conditions of this experiment, the results indicate (1) that slight increases occurred in both groups of cows in the average composition of milk from one lactation period to another in respect to total solids, fat, and protein; (2) in general, the second

and third generation cows in both groups produced milk that contained as much or more total solids, fat, protein, and minerals as their dams produced; (3) the amino acid distribution in the milk and colostrum proteins was the same for both groups of cows; (4) there was no difference in the average composition of milk produced by either group of cows that could be directly attributed to plant species grown on fertilized or depleted soil; and (5), with the exception of carotene and vitamin A, the average amount of the various B-vitamins in the milk of these two groups of cows was equal to or exceeded the average amount reported in the literature.

Cows apparently have a strong tendency to secrete milk of nearly uniform composition regardless of whether the feeds are raised on fertilized or unfertilized soils of the same type. In the case a marked deficiency of protein or minerals occurred in the ration, the first defense mechanism would be to reduce the amount of milk produced rather than to alter the composition of the milk. This appears to be a reasonable assumption when it is recalled that the original function of the cow was to secrete a natural food for the express purpose of supplying the proper nutrition to its offspring to preserve and propagate the species.

The concepts that badly depleted soils produce crops of lower nutritive value than highly fertilized soils or that the use of commercial fertilizers decrease the nutritive properties of crops were not confirmed under the conditions of this investigation.

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Nutritive Value of Milk Produced by Cows Fed Rations From Low and High Fertility Soils[1]

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INTRODUCTION

SHERMAN (1) STATES that "for the past forty years the science of nutrition has emphasized in its non-technical teaching the saying that the dietary should be built around bread and milk." It is recognized that land is the source of bread and milk and the question has arisen in the minds of many persons as to the comparative nutritive value of these foods produced on lands that differ widely in their degree of fertility. Are the food crops and the animal products obtained by feeding crops from low fertility soil equal in nutritive value to similar food products produced on high fertility soils? The plan of the experiment at Michigan State College designed to study the relation of soil fertility to the production and nutritive value of milk has been described in detail by Dexter (2). It is the purpose of this paper to discuss the results obtained from the biological assay of the experimental milks as determined by rat growth studies.

Man's interest in the nutritive value of milk is reflected in the voluminous literature published on this subject. No other single food has received more study and it is not the purpose of this paper to attempt a comprehensive review of all researches conducted in this field. The review of literature will therefore be limited to a selected group of relevant studies on cow's milk that will aid in the interpretation of the results herein reported.

Certain facts relative to the composition of cow's milk are rather generally accepted:

(1) If a series of milk samples were selected from various sources and analyzed chemically using the most precise techniques available, probably no samples would have the composition given as typical for average milk. The composition of so-called average milk and the normal ranges of these constituents are given in *table 1.*

TABLE 1—Composition of average milk

	Mean	Range
	%	%
Water	87.25	84.00—89.50
Fat	3.80	2.60— 6.00
Protein	3.50	2.80— 4.00
Lactose	4.80	4.50— 5.20
Ash	0.65	0.60— 0.80

(2) All of the samples would contain the same constituents and the variations in composition would be quantitative rather than qualitative.

(3) The analyses of composite samples of milk would more nearly approach "average values" than the analysis of single milkings from individual cows.

(4) Wide variations from average values are usually observed at the beginning and end of lactation periods.

(5) While it is generally accepted that breed may have some effect on the composition of milk, significant variations in all constituents of milk are observed in the milks from all breeds. These variations occur even when the ration is kept constant throughout the year. Eckles (3) is of the opinion that the variation is due to some individual characteristics which is a matter of inheritance.

It is obvious that the nutritive value of milk is related to its composition. Milk which contains 3.0% pro-

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tein, and 3.0% fat might be designated as less nutritious than milk which contained 4.5% protein and 6.0% fat. The high protein, high fat milk would undoubtedly have a higher market value than the less concentrated milk and would be labeled on the market as a high quality milk. Quality as used in the dairy literature and trade refers almost exclusively to market acceptance with no reference to the nutritive value of the product. As applied to a single constituent of milk, butterfat for example, quality denotes a butterfat that produces high score butter. A milk fat that produced a low score butter might have good flavor and high nutritive value and at the same time be labeled as poor in quality.

There is little or no evidence that gram for gram the protein or fat from one sample of milk would be different in nutritive value from that of a second sample of milk. As stated earlier, certain facts have been established relative to differences in the chemical composition of milk but there is no available information concerning differences in the biological value of the individual milk components or nutrients.

The source of these nutrients must be found either in the diet of the animal, in her body stores, or in her ability to synthesize more complex material from simpler ones. If the diet of the cow proved to be the determining factor in the elaboration of milk, then it would follow that the nutritive quality of milk could be altered by the kind of feed made available to the animal. It is possible to alter within limits the vitamin A and/or carotene content of milk by feeding the animal a rich source of carotene (4). On the other hand, heredity appears to be a more important factor in determining the fat and protein concentration in milk than does the diet.

Milk occupies an unique position in the category of so-called natural foods in that it furnishes significant amounts of the widest variety of nutrients found in any single food. From the nutritionists point of view the most important of these are protein, calcium, phosphorus, riboflavin and to a lesser extent fat. Furthermore, milk is one of the least expensive sources of these nutrients. The contribution made by milk toward meeting the food needs of an average man in respect to certain nutrients is shown in *table 2*.

TABLE 2—Contribution of milk to the diet

Food nutrient	Recommended allowance 45 yr.—65 kg. man	Nutrients furnished by one quart of milk	Percent of recommended allowance furnished by one quart of milk
Calories......	2,900	666	23
Protein.......	65 gm.	34.2 gm.	53
Calcium......	0.8 gm.	1.15 gm.	144
Vitamin A....	5,000 I.U.	1,500 I.U.	30
Thiamine.....	1.5 mg.	0.35 mg.	23
Riboflavin....	1.6 mg.	1.68 mg.	105

Milk Fat

In reviewing the literature relative to the effect of diet on milk fat, no reference was made to the nutritive value of different butterfats with the exception of variation in vitamin A and/or carotene content. Wiseman, Shepherd and Cary (5) summarized the findings obtained from the analyses of 4,500 samples of winter and summer butters produced in the United States and concluded that the vitamin A potency of butter is related to the carotene intake of the animal.

Other researches have been concerned primarily with alterations in concentration and physical and chemical characteristics of butterfat as affected by breed and feed. It has been demonstrated that the size of the fat globule is affected by breed (Eckles, 3), and that the level of the hay intake (6, 7) and the protein content of the concentrate (8) may affect the fat content of milk. In the latter study Balch has this to say concerning the results obtained when concentrates of different protein content were fed ". . . the variability of the response of individual cows allows little reliance to be placed on any quantitative comparison of the effects of the two concentrate mixtures, but the results leave little doubt that falls in fat content are not phenomena restricted especially to diets containing either high or low protein concentrates." The Norwegian worker, Kurt Breirem (9) demonstrated that with extreme underfeeding with both energy and protein, the percent of fat in the milk was reduced. Anaktakushnam *et al.* (10) demonstrated that the fatty acid content of milk could be altered by the type of oil used as a supplement to the ration, and Bartley *et al.* (11) found that pasture feeding increased the oleic acid content of milk but not the linoleic acid content. Hilditch (12) states that "some influence connected with the seasonal change (in fat composition) causes an increase of a few percent in oleic acid content, a slight diminution in that of butyric acid, and a more definite temporary fall in the stearic acid figures. The precise character of these seasonal changes in the milk fat of cows is not easy to establish, since other factors also come into play, notably and most certainly the slight variations in composition in the milk fat of different individuals and of the same individual as the number of lactations increases." In summary, changes in the composition of milk fat have been related most often to the quality of market products and no attempt has been made to evaluate the nutritive quality of milk fats of varying chemical composition with the exception of carotene and vitamins A and D.

Lactose

The lactose content of milk appears to be one of the less variable constituents and there is little reason to believe that diet or other factors would affect the chemical composition of this fraction of the milk.

Protein

Krauss and Hayden in 1932 (13) expressed the belief that the protein of milk would not undergo change under any system of feeding cows. Proteins, according to these workers, were described as definite chemical substances with certain amino acid combinations. If the ration did not furnish the necessary amino acids or the body could not synthesize them, milk flow would diminish. Later, in 1949, Gorden *et al.* (14) described the separation of casein into two mutually distinct components α-casein and β-casein, which occur in unfractionated casein in the ratio of 4:1. A third component γ-casein may be present to the extent of a few percent. Since the amino acid content of α and β-casein are not identical, it would seem feasible to expect slight differences in nutritive value of milk proteins depending on the quantities of the various casein fractions that are present in the given milk sample. As in the case of fat, it has been demonstrated that the concentration of protein of milk is influenced by breed, season and stage of lactation. The extensive study of Perkins, Krauss and Hayden in 1932 demonstrated little effect on the protein concentration of milk in relation to the protein content of the food. These workers did demonstrate a significant increase in the non-protein nitrogen content of milk when the protein in the feed was increased. Breirem (8) reporting the work of many Norwegian experiments states the protein content of the milk may be reduced by prolonged underfeeding with energy and protein. Duncan *et al.* (15) report little or no effect on the amino-acid patterns of milks that could be attributed to the feed of the cow.

In summary, it appears that the amount of protein in the ration is reflected principally in the non-protein nitrogen portion of the milk and not in the protein fraction. No evidence was found which would suggest that the protein from one milk is of higher biological value than that from any other milk.

Minerals

It has been accepted generally that the mineral content of milk, with the exception of iodine, is little affected by the diet of the animal. This assumption is based on studies where natural foods have been used as a source of nutrients. Archibald (16) has shown that the manganese, zinc and cobalt content of cow's milk is markedly increased when the diet is supplemented with relatively large amounts of salts containing these minerals. This is not a condition that occurs when natural foods are the source of the cow's nutrients.

Vitamins

As stated earlier, it has been shown that the carotene and/or vitamin A content of a sample milk is related to the intake of carotene. The major researches in relation to this vitamin have been concerned with the preservation of the precursors of vitamin A in feed. The vitamin D content of market milk is assumed to be negligible. Special methods of feeding and handling of the animals may increase the concentration of this vitamin in the milk but the more practical and less expensive method is the addition of vitamin D to the milk at the processing plant.

The vitamin C content of the milk is not dependent upon the food source of ascorbic acid (17). Research in this area has been concentrated primarily on methods of reducing the loss of this vitamin in market milk.

Vitamins of the so-called B-complex have been studied extensively, and it is generally agreed that the concentration of them in milk is not related to a food source, with the possible exception of B_{12}. Since cobalt is a part of the molecular structure of B_{12} it follows that this mineral must be present in the diet if the animal is to be able to synthesize this vitamin. Variations that occur in the vitamin B content of various samples of milk appear to be related to the individual ability of the cow to synthesize these components. Microorganisms in the rumen, regardless of the nutritive quality of the animal's diet, synthesize sufficient quantities of the water soluble vitamins to meet the needs of the animal and provide an excess for excretion in the milk.

EXPERIMENTAL METHOD

Two herds of cattle have been maintained on the feed produced at the Experimental Farm. The feeding pattern of these animals has been described by Ward and Weaver (18). The data reported herein include the feeding of experimental milks from 36 lactating animals, 20 of which have been fed rations produced on the low fertility soil and 16 of which have been fed rations produced on the fertilized soil. There were 20 Jersey cows and 16 Holsteins in the experimental herd. Eleven animals were studied through one lactation, seven through two successive lactations, fourteen through three successive lactations and four through four successive lactations. Fifteen of the 36 animals were daughters of the cows in the original herd and four were grand-daughters of the original herd. The distribution of the animals according to source of feed and generation is shown in *table 3.*

Collection of Milk Samples

Certain factors were considered in the establishment of the method to be used in the sampling and feeding of milk from the experimental cows. It was recognized that stage of lactation would influence the composition of the milk. Following parturition daily production of milk tends to increase for a period of time, usually 15 to 30 days. There is no way to predict when the peak of lactation will be reached for any given animal. The percentage of fat in the milk tends to vary inversely with the amount of milk secreted; the minimum percentage of fat in the milk occurs 14 to 16 weeks after the cow freshens. The concentration of solids-not fat tends

TABLE 3—Distribution of animals and number of lactations through which each animal was observed

	Cows fed rations produced on unfertilized soil				Cows fed rations produced on fertilized soil			
	Lactations—Breed				Lactations—Breed			
	Holstein		Jersey		Holstein		Jersey	
Original herd (1st generation)	K15	3	K1	1	K16	4	K2	1
	K17	4	K3	4	K18	3	K4	3
	K19	3	K5	3	K20	3	K6	2
			K9	4			K8	1
			K11	3			K10	3
							K12	3
Daughters of original animals (2nd generation)	K109	3	K101	3	K128	3	K104	2
	K129	2	K105	3	K134	2	K126	3
	K131	2	K115	3	K138	1	K132	3
	K139	2					K144	1
	K141	1						
Grand-daughters of original animals (3rd generation)	K205	1	K203	1				
	K213	1	K211	1				

roughly to parallel the concentration of fat (with the exception of lactose). The calcium and phosphorus content of milk decreases during the first month of lactation and remains fairly constant until the last 3 months of lactation. Thus it would appear that changes in milk composition occur most rapidly at the beginning and end of the lactation periods and that the milk from any one animal tends to be fairly constant in composition at the middle of the lactation period. Because of the differences in the length of lactation periods, this "middle time" could not be determined until the lactations were completed. To avoid the extremes in composition expected at the beginning and end of the lactation periods, milk for feeding was collected approximately 2 months after parturition. Eighty pounds of milk were collected, mixed, transferred to one-quart containers, quick frozen and held in the frozen state until fed. In most instances the samples of milk were held less than 6 months before being fed. At the time of feeding the frozen sample sufficient for one day's feeding was thawed and vigorously mixed to produce a milk of uniform composition. Results of the chemical analysis of all milk samples were available from the Department of Agricultural Chemistry.

Feeding Techniques

Male weanling albino rats weighing 45 to 55 grams (Sprague-Dawley, Madison, Wisconsin) were used as experimental animals. They were individually housed in screen-bottomed cages. Six animals were used for each feeding trial and were fed milk *ad libitum:* distilled water was available at all times. Weighed daily food records were obtained as well as weekly weight records for each animal. The data to be reported are based on 6-week experimental periods. Commercial evaporated milk reconstituted with equal volumes of distilled water was fed to six animals during each period of experimental feedings. The performance records of these animals were used as controls for the experimental milks. Each animal, both experimental and control, was fed a daily supplement of 0.25 mg. iron, 0.025 mg. copper and manganese per day. The mineral supplement was fed separately in order to maintain a constant intake from day to day. It had been demonstrated that animals fed mineralized milk grew satisfactorily at this level of feeding (19) although maximum growth was not to be expected under this regime. Thus if milks of superior or inferior nutritional quality would be produced under the plan of this experiment, the quality of the milk might be reflected in the growth of the animals.

At the end of the feeding period the animals were sacrificed and examined for gross lesions of the vital organs. The total food intake for each animal was computed and the protein intake calculated on the basis of the N content of the milk (Nx 6.38). The nutritional efficiencies of the milk were expressed in terms of gain in weight per gram of protein ingested over a 6-week period.

Results

A cursory examination of the nutritional efficiencies of 85 samples of milk failed to reveal any striking differences between the animals fed rations produced on fertilized soil as against those fed rations produced on unfertilized soil. There was a difference in the rate of growth supported by the experimental milks in contrast to that supported by the evaporated milk. For each series of experimental milks that were fed, a control group of six animals were fed reconstituted evaporated milk. Analysis of variance of the nutritional efficiencies of these feeding trials showed there were no significant differences in growth curves that might be attributed to litter differences, seasonal variability or environmental conditions. Thus it was assumed that these factors did not influence the growth rates of the rats fed the experimental milks.

As shown in *table 3,* both Holstein and Jersey cows were used in this study. Six of the original animals were Holsteins and eleven were Jerseys. The number of lactations varied from one to four. Three animals were discarded after the first lactation for various reasons (Ward-Weaver, 17). Fourteen of the seventeen animals in the original herd (1st generation) were studied through two or more lactation periods. In 11 of these lactations the nutritional efficiency of the milk from the first lactation was lower than that observed in subsequent lactations. The first lactations of these animals undoubtedly reflected the varied heredity patterns and varied management practices under which these original animals had been reared. When all of the animals

were placed on dry lot feeding and fed one of the two experimental rations, the differences as reflected in the nutritional efficiencies of the milk were lessened and were non-significant in subsequent lactations.

There are no published reports in the literature that describe the effects of feeding rations similar to those reported in this study over a period of two or more generations. The heifers that were born to the animals in the original herd were continued on the same diets fed to their respective dams. It was assumed that if the feed from the depleted land would have a deleterious effect on the nutritive value of the milk, this effect would be exaggerated in successive generations of feeding. Analysis of variance applied to nutritional efficiency values of the milks produced by second and third generation animals failed to show any significant differences either between feeding regimes, lactation periods or between generations. The "F" values are summarized in *table 4.* It should be emphasized that there were differences in the nutritional efficiencies of the individual milks but that the differences which were observed in this study could not be related to lactation (with the exception noted above), breed, generation or source of feed.

The nutritional efficiencies of all experimental milks produced and fed are summarized in *table 5.* It is of interest to note that, from a nutritional point of view, none of these milks could be classed as poor in quality. If the cost of producing these milks were calculated, it is possible that the return from the investment of feed and time would not warrant the production of milk under these conditions. It must be recognized however that as stated by Dexter (2) a fair share of land in this country will not support production of field crops but will provide grazing for ruminants. Poor as the feed of the cow may be, if sufficient energy is available to support even meager lactation, milk produced under these adverse conditions as reported by Duncan (19) will be a reliable source of protein, phosphorus, calcium and riboflavin. This milk may be low in vitamin A

TABLE 4—Analysis of variance of nutritional efficiencies of milks from the experimental herd

Source of variation	"F" values	Value required for significance P <0.05
RATION Fertilized vs. unfertilized	3.09	3.96
BREED—Jersey vs. Holstein		
Fertilized ration —16 animals	0.38	4.11
Unfertilized ration—16 animals	3.45	4.07
DAMS vs. DAUGHTERS 2 generations—37 animals	1.86	4.11
SUCCESSIVE LACTATIONS		
Original herd—Fertilized ration 2 lactations—5 animals	2.20	4.10
Original herd—Unfertilized ration 2 lactations—6 animals	2.96	5.14
Daughters—Fertilized ration 3 lactations—7 animals	0.00	
Daughters—Unfertilized ration 3 lactations—3 animals	1.66	3.63

and/or carotene, but inexpensive and reliable sources of this nutrient are within the reach of all persons in this country.

Before the animals were discarded, nine which had been observed through 3 to 5 lactations on the experimental rations were transferred to the "Kellogg ration." In this ration hay grown on the Kellogg farm was substituted for that grown on the experimental farm. Milk produced under this regime was collected and fed in the same manner as that described above. There was no evidence of improvement in the nutritive quality of the milks produced under the better feeding regime when the data were subjected to analysis of variance.

TABLE 5—Summary of nutritional efficiencies of experimental milks from thirty-six animals

Breed of cow and generation	Nutritional efficiencies of milks from cows fed rations grown on unfertilized soil				Nutritional efficiencies of milks from cows fed rations grown on fertilized soil			
	Lactations				Lactations			
	1	2	3	4	1	2	3	4
HOLSTEIN								
1	1.33 (3)*	1.49 (3)	1.43 (3)	1.59 (1)	1.47 (3)	1.74 (3)	1.54 (3)	1.20 (1)
2	1.61 (5)	1.23 (4)	1.38 (1)	....	1.62 (3)	1.66 (2)	....	....
3	1.22 (2)	....	....	....	....	....	....	....
JERSEY								
1	1.30 (5)	1.54 (4)	1.66 (4)	1.65 (2)	1.35 (6)	1.69 (4)	1.67 (3)	....
2	1.60 (3)	1.66 (3)	1.74 (3)	....	1.81 (4)	1.80 (3)	1.74 (2)	....
3	1.66 (2)	....	....	....	....	....	....	....

*Numbers in parenthesis represent the number of cows in each group.

SUMMARY

It would appear that, under the fertilizing practices described in the Michigan State study, there was little difference in nutritive value of the feeds produced on this land (20). No differences in the health and milk production records of cattle maintained on the feed produced were demonstrated. Although there were wide differences in the chemical composition of the milk produced under this regime, none of these differences were associated with the source of feed. It would appear that feed produced on low fertility soil does not have a deleterious effect on the milk produced by cows fed these rations. This does not suggest that quantity, vitamin A value and perhaps the butterfat content of the milk could not be altered under a different experimental plan.

The results of this experiment lend confidence to the observation that, regardless of the quality of feed furnished the cow, if sufficient feed is available to support lactation, the milk produced will be high in nutritive value. Low income families that are subsisting on marginal land should be encouraged to keep at least one milk cow as a source of high quality food for the family. A diet that is nutritionally inadequate may be transformed to one of high nutritive quality by the simple addition of milk.

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The Influence of Soil Mineral Elements on Animal Nutrition

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INTRODUCTION

A CENTENNIAL ANNIVERSARY is naturally a significant occasion in the history of an institution in the United States. With the turn of the hundredth year one is reminded that such length of time in prospect seems tremendous. But a corresponding time in retrospect seems short. The prophetic view is never so clear in its portent as is the postmortem. Hindsight has always been much more instructive than foresight. The former makes mental impressions with accompanying stronger and more disturbing emotions, hence is more of a modifier and determiner of our future behavior than is the latter.

But in an agricultural experiment station, where the living, i.e. the biological, more than the dead, i.e. the technological, matters concerns us, we have numerous and significant postmortems regularly. This seems more true now with so much emphasis on economics and sociology, when the cleaning away of disasters and the covering of defects of past mistakes occupy our thought almost to the exclusion of the preventive viewpoint. We scarcely have time to look ahead and to catch visions. We miss the chance to theorize as to how man can fit himself on to his agriculture, required to feed all of us, and into the laws of Nature, including both those recorded and those not yet comprehended.

But anniversaries are occasions encouraging us to look ahead, and to profit by means of what is behind the anniversary date. The extrapolation and the reach into the future, however theoretical and short of proof that stretch of vision is, may well "let us study things as they are and not as we have made them. Let us question our beliefs to see whether they really fit the facts. If they don't let's cast them out."[1] Anniversaries are times permitting decided shifts in viewpoints which may be a healthful experience occasionally even for some sections of an Agricultural Experiment Station and a College of Agriculture.

[1] P. H. Hainsworth. *Agriculture, A New Approach.* Page 232. Faber and Faber. London. 1954.

THE SUBJECT

The subject "The Influence of Soil Mineral Elements on Animal Nutrition" as assigned for discussion on this occasion, reminds us that the production of animals and their service to man for his food, clothing and even shelter, is an art older than man's recorded history. The importance of an adequate supply of forage for the well-being of the herds and the flocks, and thereby for man, has long been well recognized. The ancient writings in The Great Book of all books point out the need for grass. They discuss the capacity of the land to grow crops in sufficient support of the cattle lest there be strife between the herdsmen and between the herd owners. There are suggestions from ancient authors (5) to indicate that, even before the Roman era, men were aware that plants are no better than the soils on which they grow, and animals are no healthier than the plants which nourish them. Not quite so long ago, Izaak Walton, in his *The Compleat Angler* pointed out that the soil fertility is a factor in determining the quality of sheep wool, and in the tastiness of the trout. "And so I shall proceed next to tell you" (18) he says, "it is certain that certain fields near Leominster, a town in Herefordshire, are observed to make sheep that graze upon them more fat than the next, and also to bear finer wool; that is to say, that in that year in which they feed in a particular pasture, they shall yield finer wool than they did that year before they came to feed upon it, and coarser again if they shall return to their former pasture; and again return to a finer wool, being fed on the finer

wool ground. Which I tell you that you may better believe that I am certain, if I catch a trout in one meadow he shall be white and faint, and very likely to be lousy; and as certainly as if I catch a trout in the next meadow, he shall be strong and red and lusty and much better meat; trust me, scholar, I have caught many a trout in a particular meadow, that the very shape and enameled color of him was made such as hath joyed me to look on him; and I have then with much pleasure concluded with Solomon, 'Everything is beautiful in its season'."

Izaak Walton in that observation of 300 years ago saw the difference in the health, in the wool, in the quality of the fiber, in the sheen of the body color, in the quality of the muscle meat, and even in the presence or the absence of insect infestations of the beast and the fish in the fields and the streams, all related to the fertility of the soil. Our subject for discussion is then an old and a long familiar theme to the keen observing naturalist even though to us as scientists it may seem still new, strange, and not entirely proved.

THE ECOLOGICAL, OR DEDUCTIVE APPROACH

In dealing with this subject, "The Influence of Soil Mineral Elements on Animal Nutrition," one might consider two methods of approach, either (a) the inductive one which would study each inorganic element and tabulate its nutritional services to the plant and to the animal under experiment and then from that collection of data would piece together and tell the final story; or (b) the deductive one, which may be considered the ecological approach. In the latter, by studying Nature's pattern of animal placement in different areas, i.e. according to the ecological pattern, we would learn the soil differences as to mineral elements representing causes of animal presence and animal absence according to the natural processes of evolution. This is a qualitative attack and not a quantitative one. It notes the presence or absence of certain products and not how much or how well. In this discussion we shall use mainly the ecological or the deductive approach as a good beginning. We shall observe and investigate Nature's pattern and by both deduction and experimental inductions find reasons for Her locating animals on some soils and not on others. Then we might possibly deduce, therefrom, the roles of the different minerals, or the soil fertility elements in plant nutrition and thereby in animal nutrition, at least by the way they cause animal absence or the animal's failure to survive.

In this approach we shall accept the American bison's presence in great herds upon the Plains as evidence of a fairly good array of mineral elements in the soil there, or, at least, of very good combined influence on animal nutrition through the virgin forages grown there. It avoids the distorted view of nutrition which too often is mainly a fattening process, and then one of a castrated male with a very limited life span, demonstrating all too little of nutrition for the procreation and survival of the species.

By using this soil pattern with the areas of soil minerals of high and favorable influence on the survival of the bison as the guide and starting point, we are impressed with the large land areas of virgin soils of mineral or fertility contents too deficient in only one or two nutrient elements for the survival of this quadraped. We should also be impressed by the applicability of those ecological facts to our cattle herds and other livestock when the bison on those soils was duplicating our domestic animals in many details of their physiological complexities: (a) of growth, (b) of body protection against disease, and (c) of reproduction of high fecundity for survival of the species without the help (or interference) of man and his agriculture.

THE ANATOMY OF THE RUMINANT CONNECTS IT MORE CLOSELY WITH THE SOIL

Since the bison is a ruminant and the herds of the Plains lived by forages, or roughages, in considerable bulk and not by masses of grains and other concentrates, our view of the animals in this discussion may well be limited to the ruminants also. With the paunch as a digestive, or fermenting vat at the head-end rather than the tail-end of the cow's alimentary canal, the forage she ingests brings with it the soil microflora and microfauna for action in the anaerobic conditions there. By that fact she lets us connect her more closely with the soil. She profits by those symbiotic microbial relations, especially when her ingestion of urea within limits and its service as protein supplement bears the suggestion that its chemical structure with the amino nitrogen attached to the carbon serves so much more efficiently than does ammonia nitrogen or other nitrogen forms not so closely similar to the amino acid structure of protein as is urea. That she has some advantage for survival on forages only by that particular anatomical arrangement and microbial symbiosis of the paunch is suggested by the close companionship in which the pig and the chicken have always held her as one of the barnyard family by following on the heels of the cow so closely to feed on her droppings of dung but not of the urine. When the pig and the chicken have their microbial digestive helps within the alimentary canal at the tail-end of it, they are not so closely connected with, nor so completely supported by, the soil as the cow is. That the flora and fauna of the cow's paunch respond to the differences in "ash" minerals coming in the forage as feed from the soils of differing fertility was illustrated by the higher amounts of volatile fatty acids resulting from the same ration in the rumen (artificial) according as there was added the ash of alfalfa grown on the more fertile soil types or the soil more carefully fertilized (12).

We may well consider the bison as the early ruminant fauna outlining a pattern of animal survival according to fertility pattern exhibited by the mineral or inorganic elements in the soil. Then by considering the cow as a physiological duplicate to be scattered for her survival

over the same geographic area, the problem does not necessarily require our being certain that we can prescribe the array of soil fertility elements complete enough in list and functions to give certain specific results for economic management of the herds of cattle. It would be also a vain presumption to believe that we have obtained that much organized knowledge about the soil and its capacity for creating livestock. Rather by studying the soils and their natural flora in the areas where, and by which, the bison survived in contrast to the fringes and areas outside of his concentration where he was extinguished, we can detect more nearly one or two inorganic elements of which the shortage may be limiting the forage production in amount and in quality for the survival of our agricultural ruminant, the cow. Even then the problem soon becomes one of combinations and permutations, rather than single element research, in a long list when several fertility elements may be missing and many more of them may be in imbalance for the growth of the forages of sufficient quality for even ruminant species survival under the handicap of our domestication.

THE INTERPRETATION OF THE SOIL AS COMPLETE ANIMAL NUTRITION CHALLENGES WISDOM OF BOTH COW AND MAN

In considering the soil mineral elements in animal nutrition by way of the ecological pattern of the area like the United States, the size of the problem is already disheartening when, (a) by the soil as a contributor to animal feeding in a concentrated way like agriculture, less than 10 percent of the earth's crust serves for farming; and (b) by the plants, only about 5 percent of the sun's energy is used; and (c) by the animals, less than 25 percent of their feed is converted by the livestock into food for our use. This would indicate that all the weathering, all the geological, all the volcanic, or other changes on the earth's surface have not been philanthropically getting the chemical array of soil minerals collected into the soil with nutrition of domestic or even wild animals in prospect everywhere.

In considering the subject of the close nutritional connection between soil fertility and animal nutrition then, should we be appalled when the soil hinders the survival of so many domestic animals because of their multiplying numbers of diseases, their increasing degeneration, and their failing reproduction? Should we not recognize our lack of knowledge of how the animals feed themselves in Nature or how we survived when the cow as a perambulating soil chemist and soil tester went ahead of the plow to lead us to fertile soils on our westward march? Recognizing that scant collection of facts, not even organized into a science on that subject, we would seemingly have ample reason in humility to congratulate the cow on her survival in spite of us when we changed the order and have now put the plow ahead of the cow while we are acting as the chemists and the soil testers presuming to serve in the creation of her species. That we have learned about some few of the soil minerals to be applied separately, as fertilizers, for better animal nutrition by way of the forage crops we grow, indicates the magnitude of the problem. That we have not yet juggled all the nutrient elements of the soil into the proper combination; that we have not yet found the collection of crop plants to be grown on that suite of them in the field, should not be at all surprising. If then we have not arrived at the level of knowledge giving complete diagnosis of the cow's deficient health and failing reproduction, or if we have not yet written the complete prescription in commercial fertilizers from the chemist's shop by which the problems of animal nutrition will shift into regular and satisfactory profit, we should not be appalled. The many processes of creation which originate in the handful of dust have not had much more elucidation in terms of physiological chemistry even today than was implied in that allegorically reported way of merely starting them from the soil as given us in the record of a few thousand years ago. The past century has opened our minds to the soil fertility as potential plant and animal nutrition, but the *modus operandi* of each of the essential or non-essential elements in that service is a challenge remaining to be met in the next hundred years and reported at the next centennial celebration.

ESSENTIAL ELEMENTS REPRESENT WIDELY DIFFERENT GROUPS AND PROPERTIES IN THEIR CLASSIFICATION

At the outset it may be well to list the so-called "essential" elements for plant growth included up to this moment in our growing knowledge of them periodically well summarized (7). It might be well to characterize them by groupings according to certain chemical properties, reactions, or services in the physiology of the microbes, plants and animals. Among those composing most of the plant bulk, thereby the most combustible plant parts, are carbon, hydrogen and oxygen. These make up the carbohydrates into which by reductive changes three others are combined, namely nitrogen, sulfur and phosphorus. These changes of the carbohydrates, which are serving as starter compounds in the plant's synthetic performances, make the proteins and other compounds closely associated with them like the enzymes, the hormones, etc. Of these six elements just listed, four, namely the carbon, hydrogen, oxygen and nitrogen are commonly considered as coming, not from the soil, but from the atmosphere and water in the ultimate. But while the plant nitrogen of ultimate atmospheric origin, is taken by most of them from the soils via organic matter transformed there, so we are realizing slowly that carbon, hydrogen, and oxygen, also of ultimate atmospheric origin, may be going more directly into the plant as organic compounds taken from the soil. The soil is the medium through which the

fertility contributions from the atmosphere make their way. These six elements are spoken of as constituents of the "structural organic" part of the crops.

Among the elements more commonly connected with the ash, or non-combustible part of the plant, are the alkalies and the alkaline earths, i.e. potassium and sodium in the former and calcium and magnesium in the latter group. Among the elements required in trace amounts for plants are the heavy metals, manganese, iron, zinc, copper and molybdenum; and the light metal boron, to which may eventually be added the light metal silicon if we ever consider it essential for plants as its general presence in them might lead us to believe, though plants grow without it. Very recently chlorine has been demonstrated as required for plant growth (6). Other elements may be considered essential for the plant when it serves to deliver them within itself as essentials for the animal. In the case of silicon, not considered essential, much of it is found in hoof and hair of the animals. But, since it is one of the chemically sluggish performers, we have not yet decided that it is essential for animal growth even though present in larger measure in plants as, in general, they serve less effectively in animal nutrition. In the above list of seventeen elements essential for plant growth there need to be emphasized the two, namely sodium and chlorine as required for the animals in quantity and then to be added are the iodine, the cobalt, and possibly the fluorine required in trace amounts for animals but not so recognized for plants.

In addition to considering those elements coming from the soil for benefit, one dares not omit the soil-borne elements of which extra supplies there may be entering the plant for harmful effects. Among those considered non-essential but injurious to both plants and animals are arsenic and selenium. Among those both essential in trace amounts and possibly injurious in large amounts are boron, manganese, copper and fluorine.

Among the seventeen elements so far considered essential for plant growth and the three or more required for animals, the ultimate origins of four, that is, carbon, hydrogen, nitrogen, oxygen, in the atmosphere and the hydrosphere may be reason for omitting these four in discussing the soil mineral elements in animal nutrition. If so, we must concern ourselves with only thirteen elements coming from the soil by way of the plants, whether their separate services are known or unknown there, and going into the animal by way of the feed taken. They are going into the animals as combinations within the organic matter composing the forages consumed and not as minerals or salts. For purpose of this discussion let us consider the animal's taking to salts as a case of ministration of relief on our part or a kind of depravity of the animal's appetite equivalent to the chewing of bones occasionally exhibited by some of the starving cattle as an act of desperation.

ELEMENTS' ACTIVITIES FOR RETENTION IN THE SOIL AND ENTRANCE INTO THE PLANT ROOT ARE FOREMOST CRITERIA

As another classification of the mineral elements in animal nutrition, one might list their anatomical location, or their presence in larger amounts of each in different body parts. But more helpful than these "ash analyses" by areas of anatomy, are the location of the elements by physiology or function in the plant first and then in the animal. But rather than undertaking these considerations it would be helpful to note the geo-chemo-dynamics by which the elements are held in the soil and are active there in entering the plant root. Thus we would work in the element's course "from the ground up" to the animal, and not in reverse from the animal back to the soil.

Our knowledge of plant nutrition in terms of the soil-borne elements, in the form of clearer concepts of how these are held in the soil and how their activities move them from there into the plant root, has built itself up for only some of the positively charged ions. Calcium, magnesium, potassium, ammonium, nitrogen, and sodium are in this cation group now that the commonly larger quantities of them have allowed us to connect them with a negatively charged collodial clay molecule and to study their activities there. As for the trace elements with the positive charge, naturally, they can also be held by the clay except for the chlorine as an anion. But their active movement from that site and their nutritional services to the plant have not been demonstrated as is true for the above few. Their trace or limited quantities have kept them outside of the pale of our comprehension and precise tabulation.

Our concepts of how the anions or negatively charged ions of nutritive service to the plants are held in the soil and mobilized into the plant root have not taken on geo-chemical, or physico-chemical, or biochemical stature equivalent of that we now conceive for the major cations. This inorganic half of the nutrient elements, namely the anions, is still in that mental haze regarding basic chemical behaviors which we exhibit when we speak so commonly of "available" or "extractable" nutrients. When the anions are adsorbed on positively charged colloidal plastics, their exchange activities from there into the plant root simulate those of the cations held by and exchanged from the clay colloid. We have been content up to this moment with concepts only of cationic exchange when we know that no cation exists without a corresponding anion and no anion exists without a corresponding cation. We seem oblivious to the fact that for ions in nature there is no contented state of bachelorship.

Likewise our concepts of what organic compounds may be taken directly from the soil are not well developed though for the inorganic anions like nitrate and sulfate we look to decaying organic matter of the soil. For the anion phosphate, we know little more than

its "fixed" or "extractable" states, yet it is highly essential in the transformation of carbohydrates both in photosynthesis and in respiration (4). The most neglected anion may perhaps be the bicarbonate with its origin in respiration, when this is so universally present in the rhizosphere and when plant nutrition is so readily disturbed by very small amounts of fertilizer anions (chlorides and sulfates) applied on soils of lower contents of decaying organic matter. The neglect of the anions in our thinking seems to be as serious as is the neglect of the carbon compounds or the organic substances taken by the plant root as compounds directly from the soil. This latter, however, is a growing phase of our knowledge and may be all the more significant if it is connected, as some observations suggest, with protein snythesis by the plant, especially with possibly the amino acids tryptophane and methionine, so commonly deficient in forages and feeds (3).

THE LIMITING ELEMENT IS LIMITING MORE THAN ITSELF

The single element as a lone variable is the standard scientific procedure in research. However, in biological behaviors, like plant nutrition, the single varied element for plant root entrance does not vary in plant entrance itself without inducing variation in the entrance there of many others and consequent variations in the amounts of them in the final growth products (1) (14). In the cationic suite on the colloidal clay these interrelations and intereffects of the cations are demonstrated by the fact that while calcium occurs in amounts up to 60 or 85 percent of the soil's cation exchange capacity (9), magnesium makes up 6 to 8 percent, and potassium but 2 to 5 percent for good plant growth (8), yet the plant contains more potassium than of either of the other two. Also, a small variation in the potassium supply when both of the other two are constant, gives variations in the amounts of these divalents, calcium and magnasium, entering into the plant. This holds true not only under experimental control but is also demonstrated in the ecological array of plants according to the increasing degree of development of the soil under the climatic forces of rainfall and temperature (2).

Other interrelations and intereffects not only between two, but between multiple cations suggest themselves as a regular order according to increasing numbers of studies of plant nutrition using the colloidal clay and the amberlite absorption techniques for control of cations and anions, respectively, for test of the resulting variations in the plant's composition in either the inorganic or organic aspects. A growing knowledge of the significance of these ratios of exchangeable cations and their activities measured by means of soil tests and specially constructed membrane electrodes respectively (11) for the nutrition of different plants, and their respective chemical compositions, is rendering much help in managing the fertility of the soil as a balanced diet for plants with emphasis on their photosynthesis of carbohydrates mainly or on also their biosynthesis of more proteins. We are gradually modifying the plant's composition by different balances in fertility for different final plant make-up much as we balance the animal ration differently when we grow an animal than when we fatten it.

In some recent studies, the variation of the exchangeable amounts in the soil of any one of five of the inorganic nutrient elements offered brome grass induced variation not only in the entrance into the plant of the other four nutrient elements from the soil, but also gave varied synthesis by the plant of each of the sixteen measured organic compounds. These latter included four carbohydrates and twelve amino acids (13). With reference to the carbohydrate synthesis by these experimental plants, the soil-borne element, potassium, influenced the accumulation of metabolizable sugars. When potassium was high, the sugars and starch in the plants were high. But when the soil nitrogen was high, the metabolizable sugars were present in still much higher concentrations. An interdependence of these two soil-borne elements, namely, potassium and nitrogen, was thus clearly demonstrated for carbohydrate synthesis. When phosphorus, however, was the variable and both nitrogen and potassium were constant, there occurred wide variations in the concentrations of the several carbohydrate fractions, that is, the reducing sugars, the non-reducing sugars, the starch and the hemi-cellulose. That calcium played a part in the cycle of carbohydrate synthesis, a belief not held by many, was clearly established by the fact that carbohydrates as metabolizable sugars were higher in concentration in the brome grass when calcium and the other soil-borne elements were high than when calcium was low with the others all higher. These four elements, potassium, nitrogen, phosphorus, and calcium, each as a single variable modified the array in the plant of the four fractions of the carbohydrates.

In the amino acids synthesis, calcium played a fundamental role. Plants grown on high calcium and high-nitrogen soils were higher in the individual amino acids than those grown on soil low in calcium, but adequately supplied with the nitrogen. High concentrations of several of the amino acids found in the brome grass were the resultants of high calcium, moderate potassium, and high anion fertilization, namely with phosphorous, sulfur, and nitrogen. More amino acids were produced in less bulk of the brome grass than on other treatments of much higher yields of bulk. Wide differences in the relative distribution of amino acids were shown to depend very decidedly on the soil treatment.

In this study the amounts of total nitrogen as percentage of dry weight were sorely discredited as a criterion of protein quality as amino acids in the crops. Several of the amino acids essential for animal nutrition, namely isoleucine, threonine, methionine and tryptophane were quite low with high-nitrogen and high-cal-

cium treatments of the soil, yet the total nitrogen of the plants was high. In these cases most of the nitrogen was present in aspartic acid, arginine and lysine. It was shown that the application of nitrogen to the soil and the high nitrogen concentrations of the plant would not guarantee the presence of a good array of the amino acids essential for good animal nutrition.

Several amino acids were present in almost the same relative amounts in each treatment, and though variable in concentrations with soil treatments, they were present in more or less constant ratios. This held true for methionine and tryptophane in relation to some of the others. Isoleucine and threonine suggested a similar behavior. This fact suggested that these amino acids, particularly methionine, which was invariably in low concentrations, could be used as an index of protein quality with more reliability than could the concentration of the total nitrogen.

Thus, while we are apt to believe that we are setting a single element as a limiting or controlled one in the fertility of the soil as a simple, scientific experimental procedure, we cannot speak with truth of it as if a single variable were the cause of the varied plant's composition when the variations of the other fertility elements entering the plants from the soil are contemporaneously so extensive and so numerous. Thus we are in no position to single out any inorganic fertility element in the soil and believe that its variation there can be measured as a specific influence on animal nutrition so directly as ash delivery of it in the forage fed. Not even nitrogen analyses, multiplied by a factor and called crude protein, can bear much significance. The influence of any single element on animal nutrition must be viewed in terms of its service within the plant through which the synthetic performances by the forage crop render this vegetative mass more nearly a balanced diet for (a) the growing of animals, (b) the making of them more healthy, and (c) the encouragement of their more fecund reproduction. It is in these helps toward the survival of the species more than helps in serving our whims or particular desires for a certain effect, like fattening only, that we need to learn more about soil fertility as plant nutrition in order that this soil property may be more helpful in animal nutrition.

THE TRACE ELEMENTS AND THE ESSENTIAL AMINO ACIDS UNDER BIOASSAY

When the different carbohydrates, including reducing sugars, non-reducing sugars, starch, and hemi-cellulose are not each a specific requirement in supplying energy for the ruminant but serve quite interchangeably, and when the proteins are very probably a matter of a set of specific amounts and kinds of amino acids, it would seem quite clear that the production of more complete proteins in terms of those essential amino acids should be the measure of the influences by the soil-mineral elements on animal nutrition. When there has always been such serious need in humid regions for protein supplements even in the feeding for fattening purposes, this need suggests that we should visualize, not a shortage of crude proteins or nitrogenous compounds, but such of the limiting amino acids in animal nutrition connected with some limiting inorganic elements in the soil as the cause of the trouble.

With this view as the theory, it seemed well to test the shifted ratios of calcium to other elements, for example, as these modify plant compositions, since it has been the common concept that calcium-deficient (acid) soils do not grow the more proteinaceous or leguminous crops as the better feeds. By varying the amounts of the exchangeable calcium only, or of other ions in ratio to calcium, many changes were brought about in the crop's composition, as both inorganic and organic criteria can measure them, to say nothing of the wide, readily visible differences in the mass and appearances of the crop (20). It has been extensively demonstrated that the photosynthetic performances of piling up carbohydrate bulk as forages are influenced by variations in the supplies and ratios of the inorganic fertility elements. The high yields of low-protein corn running well over the hundred-bushel-per-acre mark and the increasing yields of low protein or "soft wheat" are ample evidence. But the concentration even of crude protein in that bulk is disturbed decidedly by the soil's inorganic fertility, while more disturbed is the protein which results in seed production. Still more modified by the inorganic and organic fertility of the soil is the specific array of amino acids within especially the forage but also in the seed. We need to judge the influence of the inorganic fertility according as it prompts the synthesis by the plants of a balanced suite of required amino acids in the feed crops we grow.

When we burn the vegetation in sulfuric acid in our chemical determination of crude protein and assume that all of the nitrogen is protein nitrogen, we forget that some of the nitrogen may serve in metabolism of the animal, as is true for the amino nitrogen of tryptophane, while an equal part of nitrogen in that amino acid is eliminated in unchanged chemical structure as is the indole ring nitrogen of that essential part of complete protein. In this case of the measure of the crude protein represented for tryptophane, then, we make an error of 100 percent as regards metabolizable nitrogen. For this reason it has been deemed a more refined measure of the influence of the soil fertility on animal nourishment by way of the vegetation grown, to study the shift in amino acid array in forages as influenced by the inorganic soil fertility (15) (16).

Of particular interest have been the trace elements as they influence the amino acids, tryptophane and methionine (10). Of course, the sulfur of the soil in relation to the latter, has been challenging since methionine is the significant sulfur-containing amino acid. Tryptophane synthesis by alfalfa and soybeans was decreased when magnesium, boron, manganese and

iron were withheld. The effects were shown to be similar whether in nutrient solution or in colloidal clay cultures.

The synthesis of methionine by these same legumes, alfalfa and soybeans, showed regular increase with the increased addition of sulfur to give the characteristic sigmoid curve. Here again these effects were exhibited by both the solution and the soil cultures. Sudan grass increased its methionine content also when flowers of sulfur were the fertilizer treatment of the soil. The increase of this particular amino acid occurred when there was not necessarily a significant increase in the total nitrogen. All of this indicates that we cannot expect the array of the amino acids to be contingent on a certain percent of total nitrogen. These two commonly deficient amino acids, tryptophane and methionine, may be increased in relation to some of the other amino acids, while in relation to others they seem to maintain a nearly constant ratio.

Timothy hay in its assay by rabbits demonstrated nicely that the fertilization with trace elements in addition to the major elements, according to soil tests, gave wide variation in the efficiency of the hay, supplemented by wheat, for adding weight to growing weanlings. But even with the trace elements, the wheat-timothy hay combination allowed the heat wave of 1954 to kill off the rabbits, when the stock rabbits on the same wheat supplemented by green grass suffered no losses by such death.

Relative to the possible protein in question, the addition of dried skim milk powder to the wheat-timothy hay was also an antidote for the dangerous heat wave, as was the green grass. As a repeat of the experiment under the extended heat wave, red clover hay was substituted for the timothy hay after the fatalities on the latter had mounted to 30 percent in contrast to 70 percent in the first experiment. There were no fatalities by the accommodating heat wave after the red clover was substituted. Accordingly, red clover hay and dried skim milk powder appeared as equals in preventing deaths from the heat wave by rabbits fed on wheat and timothy hay fertilized by full treatments including the separate trace elements, manganese, boron, copper, zinc, molbydenum, and then by all of these in combination.

There is the suggestion that the timothy hay, one of the grasses, under full fertilization including even trace elements is not equal to the red clover for synthesizing some of the compounds required by the nutrition of the rabbit if it is to survive the higher temperatures of the summer. But there is also the suggestion that red clover, one of the once-favored forage feeds but now about extinct on the farms, can synthesize some organic help for the survival of the rabbit on dry feed during a severe summer heat wave.

Relative to the vitamins in the green grass in contrast to the dry timothy and red clover hays, no assays were made for their content of these essentials. In some previous studies of ascorbic acid in spinach, according to the decreasing amounts of calcium and nitrogen offered as soil fertility, there was the suggestion of increased concentration of ascorbic acid with partial decrease in fertility, and then a decided decrease of this vitamin with further lowering of the fertility. There was thus a striking correlation of vitamin C with the mineral composition of the plant as dependent on the fertility of the soil in that respect (19).

Whether the rabbit discriminates in feed choice according to the vitamin C concentration was not tested. But that rabbits feeding on cracked corn grain will select the germ in preference to the endosperm to increase the protein in their feed consumption was well demonstrated. By limiting the hay as a supplement to cracked corn and supplying a fresh grain allotment after 25, 50, and 75 percent of the total had been consumed, the rabbits' discrimination had increased the protein in the part consumed by 12, 6, and 3 percent, respectively, according to weights and analyses of the remnant grain samples. Accordingly, as the higher discrimination was exercised, the gain in weight per unit of feed was less. This suggests that the rabbit does not choose to be fattened by the starch of the corn if there is protein to be selected in preference.

SUMMARY

Acccording to the preceding details reported in studies aimed to interpret the soil fertility as nutrition for the plants and the animals consuming the plants, we have not seen so much influence by the soil on animal nutrition when merely increased vegetative bulk as larger yields by the crop and increased animal weight by fattening have been the criteria aiming to interpret the influence of the mineral fertility content of the soil as it modifies the animal nutrition. Ash analyses of the crop, or of the animal, have not served as significant indicators of the influences by the soil fertility on agricultural products or their values as feed and food. They have demonstrated such in rumenology. Crude protein as an ash analysis of nitrogen multiplied by an arbitrary factor has also been disappointing. But when the protein as a suite of essential amino acids in the plants is considered, then the fertility of the soil suggests that it has influence on what organic compounds the plant synthesizes, especially the array of amino acids required as complete protein. Different crops differ in their potentiality of synthesizing these in array suggesting better animal nutrition in some crops than in others through these more complete arrays of amino acids.

Nature has given its different life forms a decidedly high safety factor. For example, we have two lungs and two kidneys, yet we find no manifestation in the malfunction of the first until there is malfunction of the second. As the result of this safety factor, subclinical troubles in animals must be numerous but go un-

recognized. So in this problem of providing the soil minerals in proper balance for animal and human nutrition, two aspects deserve special mention (1); "There is danger in assuming that no degree of deficiency exists in the absence of common incidence of observable, recognizable symptoms usually associated with gross deficiency;" and (2) "The effects of mineral deficiency are not confined to those conditions directly due to the deficiency (7)." We now recognize hidden hungers and the side or secondary reactions in organic chemistry as well as the primary one. So the soil as the starting point in agricultural production may also start many side reactions along its assembly line, working up from the soil through the microbe and the plant to the animal's nutrition. Consequently, deficiencies of subclinical magnitude have been multiplying with the decline of soil fertility, to where the incidence of the microbe is a biological suggestion of incipient body degeneration started by hidden hungers. For too long a time we have fought the microbe as if it were the entire "disease." Soil deficiencies may well be setting up the invitations for the microbes and all that we are prone to label "disease."

We are slowly coming to see that the increasing deficiencies in the soil under its cultivation have shifted the crops we grow to those of less protein and less inorganic contents. They are thereby giving less complete nutrition for the animal's self-preservation when higher fertility of the soil has been demonstrating itself as protection for the plants against fungi and insects. The larger ecological pattern has exhibited the soil as a factor via the mineral fertility elements in locating the wild animals in specific soil areas (17).

But only slowly are we cataloguing enough influences by the soil fertility on animal nutrition to catch a glimpse of the possibilities of growing healthy animals by more attention to management of the fertility of the soil with that objective as well as significant yields of crop mass per acre in mind. Perhaps we will have to wait for another centennial before enough facts about fertile soils as the basis of healthy animals can be catalogued to give us emphasis on the prevention of animal diseases via a few elements of soil origin for proper nutrition in place of cure and relief via myriads of drugs.

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Human Nutrition - Past and Present

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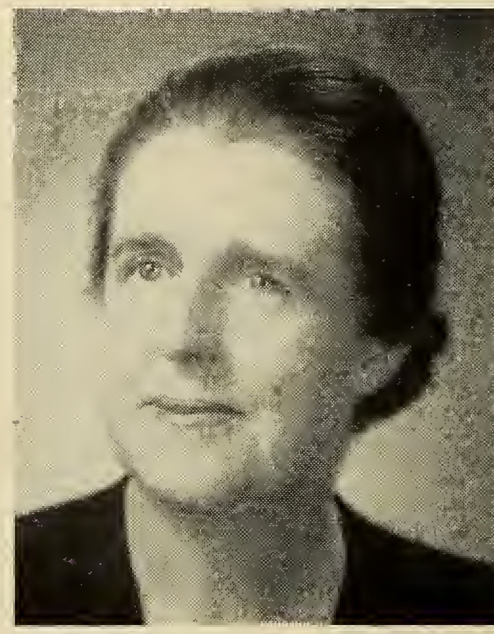

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TO WORK ON SUCH A BROAD CANVAS as to give a picture of "nutrition—past and present" in the time allotted to me means that only some of the major outlines of the pattern of progress can be sketched in. It must be left to your interest, application of your own nutrition knowledge, and further reading to fill in the details.

Let me attempt first to focus sharply on the present in nutrition and then sketch in the background along three lines, (a) the major scientific discoveries leading to the emergence of nutrition as a science, (b) the development of the tools of nutrition research, (c) some human nutrition studies, past and present.

I have tried to summarize the present status of human nutrition knowledge in twelve general concepts as follows:

SOME PRESENT DAY CONCEPTS OF HUMAN NUTRITION

1. *A number of elements and complex compounds are daily essentials in the food of man. These nutrients are broadly grouped as proteins, fats, carbohydrates, minerals, and vitamins, and there are definite interrelationships between these nutrients.*

This concept is the basis of nutrition knowledge today. The rapidity with which such knowledge has developed is shown by a look at Pavy's textbook, "A Treatise on Food and Dietetics" 1874. Pavy was an outstanding London physician and lecturer on physiology and he classifies the known alimentary principles of his day as nitrogenous principles, hydrocarbons or fats, carbohydrates and inorganic materials. Today we recognize the nitrogenous principles as proteins and know that their nutritive value depends on the kind and amount of amino acids present. The minerals that are needed are many; most recently added to the list are cobalt as part of vitamin B_{12} and molybdenum which functions in xanthine oxidase. As for the vitamins now numbering at least fifteen groups (vitamins A and the carotenes, thiamine, riboflavin, pyridoxine, B_{12}, nicotinic acid, pantothenic acid, biotin, choline, paraaminobenzoic acid, folic acid, vitamins D, ascorbic acid, tocopherols, vitamins K); the name was unknown till 1912. The nutritional function of any of them was first shown in 1915. One was first isolated chemically in 1932. Now the chemical identity of each is known.

Not only are the individual nutrients known but it is recognized that they are all interrelated in function. Certain vitamins affect fat metabolism; protein function depends on adequacy of carbohydrate and fat. The amino acid, tryptophan, and the vitamin, nicotinic acid, are interrelated; iron is utilized only in the presence of copper. These are but a few illustrations of these interrelationships.

2. *The body is in a dynamic state with a constant exchange of molecules which make up the tissues including the so-called "fixed tissues" such as fat deposits and skeletal structure.*

The dynamic state of body tissues was first demonstrated when heavy hydrogen was obtained by Urey in 1932 and Schoenheimer fed fats containing heavy hydrogen to rats and mice and was able to determine the length of time these dietary fat molecules were retained in the tissues. He found a rapid change in the fat deposits and established the theory of the dynamic state of body constituents.

3. *Enzymes are protein in nature, and enzyme systems which play a fundamental role in the processes of intermediary metabolism contain one or more of the following: protein radicle, mineral element, phosphoric acid, and a vitamin.*

This is a recent and rapidly advancing field. Digestive enzymes in the early 1900's were shown to contain nitrogen and to give some of the reactions used to identify proteins. They have since been crystallized and their protein nature established. Compounds of thiamine, riboflavin, nicotinic acid, and of other B-vitamins all function in complex enzyme-coenzyme systems which catalyze the oxidation processes and synthetic processes in the body tissues.

4. *There is a time factor with regard to nutrient supply.* This has been demonstrated for proteins. There are no reserve pools of amino acids in the body; all essential amino acids must be present in the blood stream at the same time for protein synthesis to take place. Geiger was one of the first workers to demonstrate this with rats. The practical applications in human nutrition have been demonstrated by Leverton in experiments showing the more efficient utilization of total protein when some animal protein was included in the breakfast meal as well as the evening meal.

5. *Enrichment of bread and flour, and fortification of other foods such as margarine with vitamin A, milk with vitamin D, and table salt with iodine have proved beneficial.* The story of the practical elimination of endemic goiter in this country by use of iodized salt is now a familiar one. The war-time measure of enrichment of bread and flour, now a requirement in many states, has meant the provision of a factor of safety for thiamine, riboflavin, niacin and iron for many families. The nutrition survey in Newfoundland in 1944, and the resurvey in 1948, demonstrated that the use of enriched bread and flour did cause a decrease in certain types of malnutrition. There is nothing to indicate desirability of fortification of any other foods than these just mentioned.

6. *Nutritional status of populations and individuals can be measured, at least with regard to some specific nutrients.*

The methods of measuring nutritional status are many and varied and involve physical, clinical, biochemical tests and the use of X-rays. Some of these measurements are quantitative when carried out on an individual basis and for specific nutrients. For population groups they serve as a useful screening process to detect subclinical states of nutrition.

7. *Quantitative requirements for the essential nutrients are known within certain limits,* and on this basis the Food and Nutrition Board of the National Research Council has presented a table of recommended daily allowances for nutrients.

The nutritionist not only asks what nutrients are needed, but how much. Voit (1831-1908) was one of the first to set a standard for requirement of protein although his recommended 118 grams of protein is now considered too high. As new nutrients have been discovered, balance studies have been performed whenever suitable or other technics devised, as for certain vitamins, to find the daily requirement. The present recommendations, while subject to change as new data become available, are considered to meet the needs of the majority of the population of this country and to allow a margin of safety. These allowances, however, differ from those recommended in Canada and in Great Britain.

8. *Antimetabolites are present in certain foodstuffs and have led to new discoveries about vitamins, and the effects of vitamin deficiency.*

The phenomenon of antimetabolites is one of the most interesting discoveries in nutrition. Certain substances which are structural analogs of the vitamins can combine with specific enzymes and block out the vitamin which would normally be part of the enzyme system thus preventing the enzyme from carrying out its normal function. This action of antimetabolites has made it possible to investigate the effects of vitamin deficiencies. Such work has been mainly on micro-organism but some human studies have been reported. Mueller and Vilter (Jour. Clin. Invest. *29,* 193, 1950) have fed the antimetabolite of vitamin B_6, desoxypyridoxine, to human subjects and observed skin lesions in 19 to 21 days. These lesions responded in 48 to 72 hours to daily doses of pyridoxine (B_6).

9. *Growth may be improved by the use of antibiotics.*

So much work is being done on the nutritional aspects of antibiotics that it is difficult to keep abreast of it.

Improvement in growth of chicks and young turkeys, and animals such as calves and young pigs has been demonstrated through the use of antibiotics such as aureomycin. This may possibly lead to a cheaper and more abundant meat supply for human use. Whether results similar to that for animals can be obtained in human studies is not yet clear though studies are in progress. The beneficial effects for humans may be found not in American dietaries but possibly in countries where animal protein is not available in the diet.

10. *The use of statistical methods is a requisite in the preplanning as well as the interpretation of the experimental data obtained in nutritional investigations.*

At least some elements of statistics have long been applied in the interpretation of experimental data. A newer trend is the application of statistical methods in the preplanning of experiments particularly with reference to sampling of the population. By these means the reliability of experimental data may be more confidently evaluated.

11. *Nutrition education is essential in schools and for the general public.*

Popular interest in food and "diets," the rapid developments in the field of nutrition and the spectacular results that can be obtained with the feeding of vitamins and other nutrients have led to endless food advertising and too frequently to unjustifield claims about certain foods. In fact there is a group who have become wealthy by the misrepresentation of nutrition information to the public. For these reasons it is logical that nutrition education should be considered as an essential part of the school program, and for the general public. Our people have a right to know that a state of good nutrition can be maintained by right selection of foods now available and that vitamin supplementation or further fortification of our foods is unnecessary.

It is interesting that Mulder (1802-1880) to whom we owe the term "protein" (1838) should have advocated the teaching of nutrition in the schools of Holland. He also made one of the earliest attempts to set nutritional standards when in 1847 he recommended 100 grams of protein for laborers and 60 grams for sedentary workers. Mulder was considerably ahead of his times in both of these proposals.

12. *Nutrition is a world health problem and a factor in international peace.*

Caloric insufficiency for a large part of the populations of India and the Orient, deficiency of B vitamins in the Orient, protein malnutrition and the recently identified syndrome, kwashiorkor, are problems which face the world today.

Lord Boyd-Orr has recently written (1954) "of the great advance in the different branches of science in the last forty years, none has been of more importance for the promotion of human welfare than the development in the science of nutrition. Where the new knowledge of nutrition has been applied it has saved millions from deficiency disease and where not yet applied it holds out the hope of health and increased longevity for hundreds of millions more of the world's people." In 1935, Mr. Bruce, former Prime Minister of Australia, initiated a discussion of food in the Assembly of the League of Nations and proposed a "marriage" of health and agriculture. After a three-day debate a committee of nutrition experts was set up to draw up a standard of human needs. Dr. W. H. Sebrell and Dr. Hazel Stiebeling were the representatives of this country and Sir Edward Mellanby of England, chairman.

The International Conference at Hot Springs in 1944 led eventually to the formation of F.A.O. of the United Nations and the present day efforts to improve the nutrition of all peoples of the world. Lord Boyd-Orr, first Director General of F.A.O., has said "with more than half the people in the world unable to get sufficient food for health and now believing that it can be produced in abundance, the form of government which they think can produce it quickest will gain their allegiance. It should not be forgotten that communism was born of hunger."

The above are a brief summary of the major concepts of human nutrition today. Several of these have been developed in the last quarter of a century and nutrition itself has achieved the status of a science only within this twentieth century. The first appointment of a university professor of nutrition in this country was in 1921 when Dr. Mary Swartz Rose received that appointment at Teachers College, Columbia University and it was 1932 that the first Ph.D in nutrition was granted at that institution.

Time has not permitted the discussion of each of these concepts in detail, but the very nature of these concepts indicates the comprehensive understanding that man possesses today of the kind and amount of nutrients that are needed by the body, and the intricate chemical changes which go on within the organism. Here obviously is a science that has drawn not only on every branch of chemistry, but also on physics, radioactivity, anatomy, physiology, bacteriology, medicine, sociology, agriculture and biometry.

Here also is the reason why nutrition research today is rarely the work of one individual but is teamwork demanding the skills of specialists in various areas of science.

To understand why nutrition is one of the newest of the sciences we must look back through the pages of history and trace the development of the experimental method and of scientific concepts.

MAJOR SCIENTIFIC DISCOVERIES LEADING TO EMERGENCE OF NUTRITION AS A SCIENCE

Science began with the Greeks. Empedocles (502-432 B.C.) a Greek physician introduced the idea of four elements: fire, water, earth and air. These four elements were believed to be made up of combinations of the four qualities: hot, dry, cold and wet. Hippocrates (460 B.C.) wrote on nutrition and gave us the four humors of the body: blood, yellow bile, phlegm and black bile. Science could not progress far on such concepts as these but Galen (130-200 A.D.) made valuable contributions in medicine and anatomy. With the collapse of Greek and Roman civilization and the period of the Dark Ages there was no interest in science. Galen's teachings were maintained and no one was permitted to suggest otherwise until the fourteenth century when there was a rising interest in general learning and in science. With the introduction of printing in the fifteenth century and the voyages of Columbus, men's minds were at last prepared for new ideas.

These new ideas began to develop when Vesalius (1514-1564), the Flemish-born medical student determined to dissect for himself and made his name immortal with the publication (1543) of his book, "On the

Structure of the Human Body." He laid the basis for physiology and the voice of authority was at last overthrown; the spirit of independent investigation began to sprout.

In the field of chemistry Phillippus Aureolus Theophrastus Bombastus von Hohenheim (1493-1541), or Paracelsus, as he called himself, burned the books of Galen and began to experiment for himself. Mixture of braggart, drunkard, mystic and keen thinker, he started a new era in chemistry. Paracelsus rejected the Greek elements and substituted mercury, sulphur and salt; he turned chemistry away from the alchemist's search for the transmutation of metals, to the preparation and purification of chemical substances.

Vesalius started anatomy on the pathway of progress and Harvey (1578-1657) accomplished the same for physiology and laid a foundation stone for nutrition when he made one of the greatest of all discoveries in science and published his classic (1628) on the circulation of the blood; he gave us clear understanding at last of function within the body. Harvey himself asked the question about circulation, "Is this for the purpose of nutrition?"

Along with circulation, two other main streams of knowledge in physiology had to be explored before modern nutrition knowledge could arise. These were respiration and digestion. Contributors to understanding of respiration were the chemists of the seventeenth and eighteenth century. Robert Boyle (1627-1692), so well known for his gas laws, began the scientific study of respiration in 1662 when he showed that a candle in a chamber exhausted of air went out, and a mouse under similar conditions died. Richard Lower (1631-1691) observed the change in color of arterial and venous blood in passage through the lungs and attributed this to the absorption of air from the lungs; James Black (1728-1799) the Scottish chemist rediscovered fixed air or carbon dioxide and showed that it was given off in the breath of animals. Joseph Priestly, the Unitarian preacher who loved to experiment, discovered oxygen. However, he did not comprehend the significance of what he had found and had to leave it to Lavoisier (1743-1794) to give meaning to his discovery. While Lavoisier made no discoveries himself, his was the mind that could interpret the work of the eighteenth century chemists; he introduced modern chemical terminology and made possible the writing of formulae. He showed that respiration uses oxygen, and solved the problem of oxidation. Lavoisier laid the foundation for metabolism studies by measuring calories or the amount of body heat an animal gave off in melting ice, and showed that life is a chemical process.

Regnault, in Paris in 1849, with a respiration apparatus he built in which small animals could be enclosed, showed that the amount of oxygen consumed and CO_2 exhaled differed with the food eaten, and also with the size of the animal.

Further study of respiration and building of a calorimeter for studies on man by Voit (1831-1908) and Pettenkofer (1818-1901) opened the way for metabolism studies which were continued by Voit's pupil Rubner who established the law of conservation of energy in the animal body. Another of Voit's pupils, Atwater, established calorimetry in this country.

At the beginning of the nineteenth century, oxygen and nitrogen were well understood and work with these elements and compounds of carbon opened the way for the new biochemistry under the leadership of Liebig (1803-1873) and the German school of chemists. Protein metabolism dominated the scene until well into the twentieth century, although the importance of several minerals in nutrition was recognized in the latter half of the nineteenth century. In 1880 several investigators tried feeding mixtures of pure ingredients to animals but failed to get growth. The minds of scientists were not yet ready to accept the idea of vitamins. Clinical studies on deficiency diseases, the quantitative animal feeding experiments of Hopkins (1906-1912), the inspiration of Funk (1912) in coining the term vitamin, and the experiments of McCollum, and of Mendel in 1914 at last ushered in the study and eventual isolation and synthesis of the vitamins.

These are but a few of the workers and the high spots of the growth of science through the centuries: the slow unfolding of Greek science, lost in the Dark Ages, starting up again with anatomy in the sixteenth century, the discovery of circulation and development of the use of the microscope in the seventeenth, the beginning of modern chemistry in the eighteenth, the rise of physiology in the first half of the nineteenth, and the growth of organic and biochemistry in the second half of the 19th century, the discovery of the vitamins in the twentieth century, the isolation of the individual nutrients and today the study of total nutrition and all its interrelationships along with a broadening understanding not only of the chemical and physiologic processes but of the significance of nutrition in the health and well-being of all peoples of the world.

The names of many great investigators and important discoveries in science that have contributed to present knowledge of nutrition have been omitted. Time to present this material, rather than ignorance, is the explanation for the omission.

DEVELOPMENT OF SOME TOOLS OF NUTRITION RESEARCH

Nutrition research is dependent not only on progress in scientific concepts but on laboratory tools and equipment to carry out the experiments to verify various hypotheses.

Determinations of chemical composition alone do not tell the nutritive value of a food and therefore biological studies have always been essential.

Human nutrition of the past has been largely dependent on animal experimentation and scarcely a living creature has failed to render service in some way. Bees were used by Scheele (1742-1786), the Swedish apothecary, in a glass chamber filled with oxygen to show that they died when the oxygen was used up.

A horse and a lactating cow were used in 1839 by Boussingault (1802-1887) in what were the first nitrogen balance studies on animals. Continuously since, farm animals of every kind have been used and the agricultural sciences have contributed much to our basic knowledge of the physiologic function of nutrients.

Reaumur (1683-1757), whose name is given to a temperature scale, used birds for his well known studies of digestion that were undertaken when he was nearly seventy years of age. He used a pet bird, the kite, which ejected what it could not digest and so, by having the bird swallow perforated tubes filled with various foods, he was able to study gastric juice and its action and show for the first time that the old view of digestion as a fermentation process was wrong.

Geese served to demonstrate the conversion of carbohydrate to fat (1889). Fowls were the tools for Eijkmann's (1858-1930) contribution to the knowledge of beriberi, and pigeons were the means R. R. Williams used for his studies leading to the isolation and identification of vitamin B_1 or thiamine. Chicks long served as assay material for vitamin D determinations.

Dogs were used by Magendie (1783-1855), the French physiologist and teacher of Claude Bernard (1813-1878) whose work there has not been time to mention. Magendie in 1816 fed dogs single protein-free substances and found that they died in a month or less; this could be prevented by feeding protein-containing foods and thus the necessity for nitrogen-containing foods for maintenance of life was established. On some diets the dogs developed lesions around the eyes but Magendie was in no position to recognize vitamin A deficiency symptoms—that came just 100 years later. Lusk also used dogs for numerous nutrition studies. In the field of rickets and vitamin D studies (1918) Edward Mellanby used puppies. His wife May Mallanby used the same puppies and added much to our knowledge of vitamin D and dental tissues. Dogs, too, were the means of study of the antipellagra vitamin by Goldberger; and Elvehjem in 1937 succeeded in preventing and curing blacktongue, the analog of pellagra, in dogs by administration of nicotinic acid.

The guinea pig was used by Lavoisier for his studies on body heat; and in 1907 Holst and Frolich were the first to produce scurvy experimentally in guinea pigs and from that time on innumerable guinea pigs have been sacrificed in experiments on vitamin C.

Rats and mice are probably the most familiar of all experimental animals in nutrition research. One of the first records of the use of rats for nutrition studies is that of W. S. Savory (Lancet 1. 381. 1863) who performed nitrogen balance experiments and showed that non-nitrogenous diets failed to maintain life.

Monkeys are obviously the ideal animal for human nutrition investigation, but lack of ready supply and expense have been a deterrent. However, a colony now established in this country is making possible more experimental work; especially interesting are studies on dietary factors in dental caries in monkeys.

The first modern experiments which showed that iodine was essential for the prevention of simple goiter were performed with brook trout. (Marine and Lenhart, Jour. Exp. Med. 12 311. 1910). Hamsters, cockroaches, larvae, cats, and rabbits have all served as experimental tools.

To study intermediary metabolism the standard procedure has been the analysis of intake and output in the human, and in animals the measurement of changes in body composition or changes in the amount of metabolites present in the tissues. Obviously this method gave limited information and much was left to conjecture. New tools became available in 1935. In that year the first biological experiments with isotopic compounds were carried out with fats with deuterium or heavy hydrogen as part of their chemical structure. This powerful new tool of the isotope made possible new discoveries since the living organism does not discriminate between isotopes of the same element and treats them all alike. Through feeding experiments with mice and rats receiving deuterium inserted in fatty acids, Schoenheimer and co-workers showed the pathways of synthesis, interconversion and degradation of fats and demonstrated that the body fats are in a state of flux.

Similarly, heavy nitrogen made possible a new technique for investigation of protein metabolism and, beginning in 1939, Schoenheimer and associates published an extensive series of papers on the amino acids and their rate of reaction in the regeneration of protein in the body. Ready availability of radioactive isotopes of many elements has extended the use of this tool to the study of intermediary metabolism of many nutrients. The human nutrition laboratory of today uses the Geiger counter and its various adaptations for learning where radioactive substances are deposited in the body; respiration calorimeters for determination of energy expenditure; the Beckman spectrophotometer for measurement of metabolites in as little as .01 ml. of body fluid; and X-ray apparatus for the study of bone density and calcification in the living organism. Biopsy techniques are used on humans, and microbiological methods have largely replaced the animal assay methods. Bacteria and yeasts are used for quantitative determinations of vitamins giving results in 72 hours or less as compared to 4 to 8 weeks when rats were used. Molds such as *neurospora* are used for amino acid studies.

SOME HUMAN NUTRITION STUDIES, PAST AND PRESENT

We know that in many experimental studies man does not respond in the same way that animals do. The best subject for the study of human nutrition is man himself, but obviously there are limitations to the type and extent of such studies and we have been dependent on animals for much of our information. Nevertheless, there have been numerous studies on humans, and it is to be hoped that someday a monument will be raised to the children in orphanages who have added to the sum of knowledge about pellagra, dental decay, human growth rate, and the effects of adding different foods and nutrients to their diets.

Some of the human nutrition studies which follow were chosen either because of their historical significance or because they opened up new lines of work and new ideas.

One of the earliest, if not the first nutrition experiment on record is that in the Bible in Daniel 1: 1-15, though one might question whether such striking differences could be observed in 10 days on a diet of pulse and water.

The picture of the nutrition worker of today in his well-equipped laboratory is in striking contrast to that of the familiar figure of Sanctorius (1561-1636) as he is shown in the textbooks, carefully weighing himself as he eats weighed amounts of food. Sanctorious has been referred to as the father of human metabolism studies. He struggled with the problem that if he weighed himself and the food he ate, and weighed his excretions, they were not the same although his body did not gain in weight from day to day. He explained the differences as "insensible perspiration" and in his aphorisms he wrote, "If eight pounds of meat and drink are taken in a day the quantity that usually goes off by insensible perspiration in that time is five pounds." Sanctorius was an intelligent and shrewd observer with a passion for research. He could see the problems but he could not solve them; the scientific concepts and the necessary laboratory equipment were not yet devised. In fact more than three hundred years were to pass before chemistry was sufficiently advanced to provide these answers on human metabolism.

In the middle of the eighteenth century James Lind (1716-1794) published results of his classical experiment on scurvy; the first human nutrition experiment with carefully planned controls. He says "On 20th May, 1747 I took twelve patients in the scurvy. . . . Their cases were as similar as I could have them . . . They lay together in one place, and had one diet common to all, ... Two of these were ordered each a quart of cyder a day. Two others took twenty-five drops of *elixir vitriol,* three times a day . . . . Two of the worst patients . . . were put on a course of sea water. . . . Two others had each two oranges and one lemon given them every day. . . . The two remaining patients took the bigness of a nutmeg three times a day of an electary recommended by a hospital surgeon. . . . The consequence was that the most sudden and visible good effects were perceived from the use of the oranges and lemons; one of those who had taken them being at the end of six days fit for duty." In spite of the beauty of this experiment and clarity of the results it was 48 years later before serving of lemon juice was enforced in the British Navy. Men still died from scurvy in 1912 as you will recall in Scott's expedition to the South Pole; and it was 1932 before C. G. King isolated vitamin C from lemon juice.

Scurvy claimed another original investigator when in 1770, William Stark, a young physician in London undertook dietary studies upon himself, conducting twenty-four experiments of 5 to 30 days each, and each period with a different diet. Body weight, and weight of food and excreta were carefully recorded along with the different effects of each food on the body to find out in his own words: "whether for instance, it agrees or disagrees with the stomach, is more or less nourishing, has the quality of invigorating, or of occasioning laziness and inactivity, if it enlivens or deadens the faculties, and if it creates or alloys the several appetites and desires." So little nutrition information was available at this time that Stark's experiments resulted in his death from scurvy and probably B-vitamin deficiency, at the age of twenty-nine.

Lavoisier followed up his animal respiration studies by making the first measurements of energy expenditure by a human being. Madame Lavoisier has preserved this historic contribution in a charming laboratory sketch showing Lavoisier's associate Seguin, breathing through a mask into a series of flasks in which oxygen and carbon dioxide were measured.

It was stated earlier in this paper that knowledge of circulation, respiration and digestion were essential before metabolism studies could be properly undertaken. In the field of digestion Spallanzani (1729-1799) at the University of Pavia followed up the work of Reaumur on birds and studied gastric digestion on himself by swallowing small linen bags containing meat and bread (1780). Thorough understanding of gastric digestion was not obtained, however, until 1883 when William Beaumont, a backwood physiologist as Osler has called him, published his classic "Experiments and Observations on the Gastric Juice and the Physiology of Digestion." "The man and the opportunity met" says Osler, on June 6, 1822 when the French Canadian voyageur, Alexis St. Martin, while at Fort Mackinac, Michigan, received a gunshot wound in the breast. Under the care of Beaumont, the man recovered and the wound healed leaving an opening into the stomach. Beaumont conceived the idea of studying the processes of digestion through the stomach opening. The story of his difficulties with his recalcitrant subject is well known. Many of the conclusions from his several hundred observations still stand today.

From the middle of the nineteenth century human studies became increasingly common. The techniques for nitrogen balance studies on man were perfected by Carl Voit (1831-1908) and human balance studies for many nutrients have continued to be one of the main methods for determining quantitative requirements for human subjects of all ages. The work of Russell Chittenden (1856-1943) should be mentioned in this connection. Chittenden experimented upon himself and his associates (1905), also on a squad of soldiers and a group of athletes on low protein diets. He reported that vigor and nitrogen equilibrium could be maintained in these subjects on the equivalent of 44 to 53 grams protein per day for a man of average weight. These and succeeding balance studies to determine protein requirement have been open to criticism and the question is still being investigated.

The isolation and identification of the amino acid threonine by W. C. Rose and co-workers in 1935 made it feasible to use purified synthetic diets for the first time for the human study of individual amino acids. This has been accomplished by Rose over a long period. He began the use of synthetic diets in 1942, and reported some of his data in 1949 on healthy male adults who were maintained on a diet of cornstarch, sucrose, butter fat, corn oil, inorganic salts, vitamins and amino acids. Eight amino acids (valine, leucine, isolencine, threonine, methionine, lysine, phenylalanine, tryptophan) have thus been shown essential for nitrogen equilibrium in the adult. By similar experiments Rose has also been able to determine the average minimum requirements for these amino acids by groups of adult subjects. This is a dramatic culmination to the work begun by Magendie in 1816 when he showed that nitrogen-containing food was essential for maintenance of life of the dog.

Another human study which illustrates progress in a different area of nutrition is that of Marine and Kimball in 1921. They used some 6,000 school children in Akron, Ohio where simple goiter appeared to be endemic. In one of the early large-scale scientifically controlled human experiments they demonstrated the efficacy of iodine in drinking water as a preventive of simple goiter and confirmed the theory that deficiency of iodine in food or water was responsible for the development of endemic goiter.

Time will permit reference to only one other study of humans although it would be desirable to tell of the many controlled studies on growth and development of children, the influence of diet in pregnacy on the health of mother and infant, and the studies of the psychological aspects of nutrition and food habits. The last study to be mentioned is unparalleled in nutrition. It embodies all the principles of nutrition discussed here, and utilized practically every known nutrition test and current method of analysis. There were adequate controls, and a sufficient number of selected test subjects studied for a long enough period of time to permit satisfactory statistical treatment of the data. I refer to the 2-year (1944-1946) study under the leadership of Ancel Keys of the Laboratory of Physiological Hygiene of the University of Minnesota, on the effects on young men of a semi- starvation diet, and the problems of dietary rehabilitation. This study culminated in 1950 in a two-volume publication "The Biology of Human Starvation" which stands as one of the great landmarks in the study of human nutrition.

SUMMARY

I have attempted here to summarize present nutrition knowledge in a group of concepts; to trace briefly the development of scientific thought leading to the emergence of nutrition as a science; to describe some of the tools of nutrition research; and to indicate some of the classical studies past and present in human nutrition.

Most of the nutrition studies so far reported have been for comparatively short periods of times, short at least when one considers the life span of man. Controlled studies over a number of years, so-called longitudinal studies, are needed to answer the problems of effect of variations in intake of calories and nutrients.

Progress in nutrition has been and will continue to be dependent on the growth of knowledge in other sciences, on the laboratory tools and equipment available, and on the keenness of observation and on the imagination of the scientists to develop new ideas.

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Interrelationship of Quality of Soil and Human Nutrition

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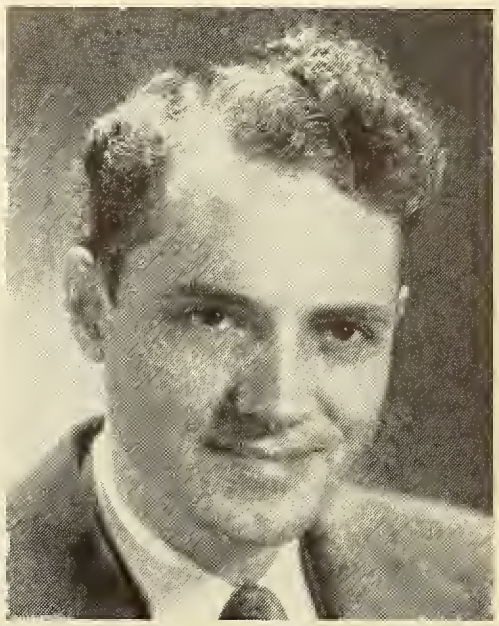

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ONE MAY READILY CITE EXAMPLES of malnourished populations existing on soils of low fertility and, by way of contrast, well nourished populations living on well managed fertile lands. What conclusion can one draw from such observations? Which is cause, which is effect? In practical human nutrition, what is the nature of these interrelationships, and how may we profit most from our knowledge of them? Such are the questions with which I propose to deal. In so doing we must approach these questions without prejudice and with the broadest interpretation of the title, "Interrelationships of Quality of the Soil and Human Nutrition."

Let us examine this interrelationship from the standpoint of a few of the urgent diseases of manlutrition in the world.

Endemic goiter:

Endemic goiter is probably the most widespread of all deficiency diseases. It is due to a lack of iodine in the diet. It affects both man and beast in the regions where it is more severe. In both, the administration of adequate iodine is preventive. Indeed, promotion of effective measures for increasing iodine in the diet is a current program of The World Health Organization (1).

In many regions, investigations have revealed an inverse relationship between the incidence of goiter and the iodine content of the soils and water, and the foods grown on the soils (2, 3). These latter two are obviously but indicators of soil content of the element.

This classical relationship constitutes the only established example of a direct causative role in the etiology of a human deficiency disease of a specific nutrient lack in the soil.

Iron deficiency:

Another seriously widespread deficiency in man in the world-at-large is iron. Iron deficiency is a disease especially prevalent among the underdeveloped agricultural nations, and it is sometimes erroneously attributed to a lack of iron in the soil. Epidemiologic studies show that the disease is most prevalent among children and women of the childbearing age—a reflection of the greater needs of these groups. Only a portion of the members of these groups develop the anemia. The adult diet usually contains rather abundant quantities of iron, hence one must look elsewhere for the etiology of the deficiency.

Consideration of the physiology of iron absorption, excretion and loss, and of the general environmental conditions, the parasitism, the meager medical care facilities, the infant feeding practices, etc., adequately account for the deficiency (4). I know of no area in which there has been satisfactorily established a direct relationship between iron content of the soil, the diet, and the occurrence of iron deficiency anemia.

Other inorganic elements:

Indeed, critical examination of the evidence concerning the occurrence of human deficiency diseases as a *direct* consequence of lack of an inorganic nutrient in the soil leads to disappointment. As stated by L. A. Maynard (5) ". . . with the exception of the long-recognized case of iodine, none of the reports which have suggested correlations between soil deficiencies and human diseases have been based on studies or observations which were sufficiently critical to establish direct relationships."

Protein malnutrition: (6, 7, 8)

We have heard much in later years of the scourge of protein malnutrition—variously termed Kwashiorkor, Sindrome Policarencial Infantil, mehlnahrshaden, "Les infant rouges du Cameroun," etc. The mere multiplicity of name indicates its wide occurrence. This disease of infants is characterized by edema, skin and hair changes, hypoproteinemia, diarrhea, emaciation, and fatty and other changes in the liver. It occurs among infants in areas where the foodstuffs making up the diet contain less than 2 gm. of protein per 100 calories. It is uncommon in areas where the diet is composed chiefly of foods containing 4 gm. or more of protein per 100 calories. Protein malnutrition, therefore, occurs where cassava, plantains, bananas, sweet potatoes, rice, maize, "aqua dulce" and similar high-carbohydrate products make up the diet of the infant—and where milk, the better legumes, and other foods of good protein content are scarce and prohibitively expensive.

This, like most dietary diseases, is an economic and cultural disease. But one must agree with Autret and Behar (8) that "The primary preventive measure is to increase the production of animal and vegetable proteins." Here it is apparent that the fitness of the soil for appropriate crop production and the fertility to sustain yields at effective levels share in land-use practices and education.

Protein malnutrition, regardless of the name applied, is one of our greatest robbers of infants' lives. It is not traceable to the absence of a specific soil nutrient, but its correction and prevention must be based upon proper understanding and consideration of soil and the crops which can be grown in the region to supply the nourishment required by the inhabitants of that region, along with a realistic recognition of the "real needs" of the underdeveloped countries (9).

Pellegra:

The thesis developed concerning protein malnutrition may be further illustrated by pellagra. Indeed, pellagra, although undoubtedly a niacin deficiency disease, might even be considered as a protein deficiency syndrome. The disease is seen as a dermatitis, with, in its severer form, glossitis, diarrhea, mental changes, and often symptoms of associated deficiencies. It occurs in economically impoverished regions or among groups whose diet is predominantly maize, predominantly so because the greatest yield of easily stored cereal calories per acre may be obtained from maize.

Soils of low fertility, inefficiently managed, under agricultural systems which perpetuate bare subsistence farming, coupled with ignorance and cultural underdevelopment, all combine to produce the nutritional deficiency of pellagra. The attack on the problem is multifacet. Agriculture must be made profitable through rebuilding of soils, the arrest of erosion, the replacement of surface scratching by deep plowing, intelligent animal farming along with carefully weighed crop changes, all in conjunction with general cultural development. At times the socio-economic system itself must be corrected, as implied by Goldberger in 1927 in discussing the disease among tenant farmers in the South (10). But this takes us beyond our subject matter. The pertinent points here again are that agricultural productivity must be increased, that soil fertility is basic to any effort in this direction, and that no single directly connected elementary deficiency in the soil is responsible for the disease itself.

We could cite similar relationships for other great problems of nutrition—starvation, beriberi, scurvy, and avitaminous A. Consideration of the occurrence of these in other than in disaster areas leads to the conclusion reached in 1951 by G. M. Culwick (11) as a result of the study of diet in the Gerzira irrigated region of Sudan, viz,

"The survey results hammer home the fundamental lesson that the primary limiting factor in matters of diet is economic necessity. So long as a population is living at bare subsistance level, its field of choice is negligible. It keeps itself alive (or not) on whatever is at hand. The first step in improving its nutrition is to loosen the grip of poverty. Only when that has been done is there scope for food education. Conditions in the scheme today demonstrate the very considerable extent to which, given a reasonably good food pattern at the top of the social ladder, dietary improvement may follow spontaneously in the wake of purely economic development not directly concerned with food and nutrition at all. Complementary development on the educational and social side is then required in order that the possibilities of the new situation may be utilized to the best advantage, and to prepare the way for the evolution of a food economy organized on lines more suited to the changed conditions in which the community lives."

The roots of any such development are nurtured by agriculture, but watered by education.

Other considerations:

The obvious nature of such generalizations has led some missionary spirits to seek the prevention of many ill-understood plagues of mankind in hypothetic mystic properties of soil, and to propose their prevention by organic treatment of soil, use of trace elements, change in soil flora, use of manures with vitalistic "natural" properties, etc. A great list of diseases could be compiled which, with well-intentioned but mis-directed enthusiasm, have been attributed to soil impoverishment or adulteration. These include multiple sclerocis, poliomyelitis, cancer, atherosclerosis, hypertension, mental diseases, and other conditions incompletely understood by medical science. Indeed, the proponent of such hypotheses seems often to reason that because one cannot disprove the idea it must be true.

Or, to express it as did Hiliare Belloc in describing The Microbe:

"Oh, let us never, never doubt, What nobody is sure about."

Conclusions:

Correction of the major nutritional problems of the world today must put into proper perspective the relationships between soil productivity and human nutrition. Action programs must deal with tangible realities, and not with nebulous revelations of untested prophets. Research may deal with untested hypotheses, but imagination must not bias the data, and a hypothesis must not be confused with theory or with fact.

Refreshingly applicable to the subject of this discussion are the concluding comments of Sir Humphrey Davy's 1814 course of lectures on Agricultural Chemistry (13):

"There are sufficient motives connected both with pleasure and profit, to encourage ingenious men to pursue this new path of investigation. Science cannot long be despised by any persons as the mere speculation of theorists; but must soon be considered by all ranks of men in its true point of view, as the refinement of common sense, guided by experience, gradually substituting sound and rational principles for vague popular prejudices.

"The soil offers inexhaustible resources, which, when properly appreciated and employed, must increase our wealth, our population, and our physical strength. . . ."

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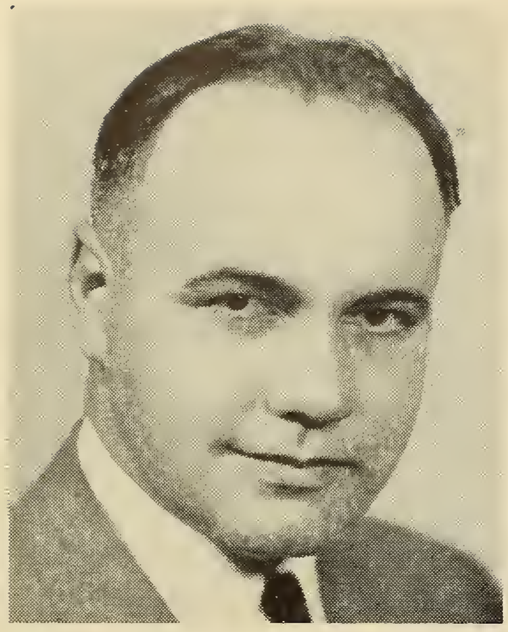

DR. L. E. CLIFCORN, Director of the Fundamental Research Division of the Continental Can Company, Inc., Chicago, Illinois. Dr. Clifcorn recently was elected to the presidency (1955-56) of the Institute of Food Technologists.

Commercially Processed Foods as Related to Human Nutrition

By L. E. Clifcorn

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FORTUNATELY THE AMERICAN FOOD INDUSTRY has an alert and responsible interest in the health and well-being of the consumers of its products. Its objectives are to make a wide variety of foods easily available at low cost, provide a palatable and nutritious diet satisfactory to populations living under widely different conditions, and afford a profit to those engaged in the several operations of packaging and distribution.

Nicholas Appert's discovery of the art of preserving food 150 years ago ranks as one of the great discoveries of mankind. This was particularly true after the mysteries of the preservation of foods by heat were removed by the bacteriological work of Louis Pasteur. However, the ultimate success of canning depended upon the development of a suitable package.

Appert used regular and special mouthed bottles in his work since they were the "most impermeable to air" type of containers then available. Peter Durand in 1810 conceived and patented the idea of using "vessels of glass, pottery, tin (tinplate) or other metals or fit materials." He recognized the virtues of tin-coated, iron containers for use with Appert's method and developed the English "tin cannister" into a hermetic container from which we derive our term "tin can." His cans were made from tinned iron sheets cut to size and soldered by hand. Thus the forerunners of the modern tin can were created.

Since the dawn of civilization, man has been concerned with the problems of preservation, packaging and storage of foods. Present day packaging has come a long way from the handmade tin container, the barrel or keg, the burlap bag or earthenware jar. Although we may not always think that the package was important in the drying, smoking and salting of food, a package had to be developed for processing, storage, and distribution, whether it was only leaves or husks of plants, skins from animals or woven baskets. With the development of glass, pottery, and wooden vessels, other food preserving methods such as pickling and fermenting were made possible. Many of these culinary arts remain with us today. Constant improvements are being made and new and better materials are constantly being introduced. The results are obviously more, better and cheaper packages for foods of all types.

The preservation of foods at the times and locations of their abundance, for later consumption throughout the world represents a most valuable service of the food industry to mankind. Few people realize the importance of processed foods until they are brought to understand how their living would be affected without them. The movement of people away from the soil would be quickly reversed, and large populations would be forced to migrate to more fertile lands and more moderate climates.

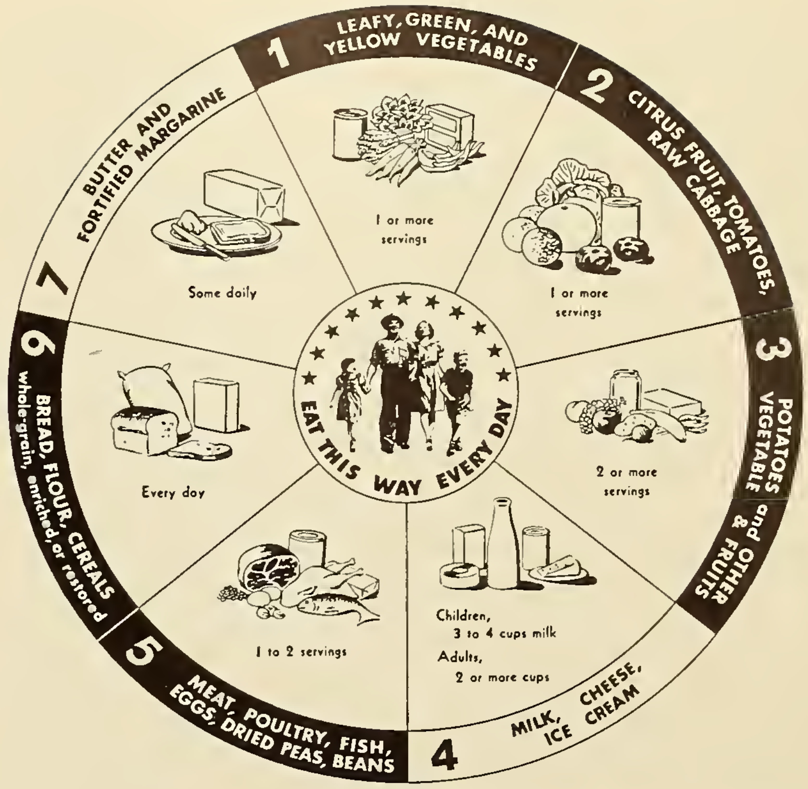
The success of canning must first be credited to our victory over bacteria, namely, our ability to effect sterilization by heat. Next in importance is the factor of palatability in processed foods. Foods must taste good to be eaten. People eat what they like and if a food is not eaten its nutritive value is of little importance. In addition many social events center around the enjoyment of good food. Food processors know that their products must taste good and have placed major emphasis on this factor. The third important factor for consideration in processed foods is that of nutritive value on which great emphasis has been placed. Since people eat what they like, it is imperative that the food industry accept the responsibility of preserving to the greatest degree the nutrients with which our natural foods are endowed. Good raw products must be attained to produce good processed foods. The nutri-

tional qualities cannot be improved by processing. Even though the struggle for food in these United States is relatively non-existent, dietary studies have shown that we need 10-25 percent more milk, 10-25 percent more butter or oleomargarine, 25-70 percent more tomatoes and citrus fruit and 50 percent more green, yellow and leafy vegetables for optimum nutrition. With the consumption of over 50 percent of the fruit and vegetables in the American diet coming from cans, these estimates represent a large potential future for processed foods. Research on improved flavor of canned fluid milk or canned concentrated milk may lead to an increased consumption of milk by taking advantage of the peak production periods of milk more efficiently, enabling a more relaxed schedule and wider range of distribution.

HOUSEWIFE IS CONTROLLING FACTOR IN FOOD INDUSTRY

In the United States of America, the housewife is the greatest controlling influence of the canned food industry. Except in the rural areas she has become dependent upon food from commercial sources to supply her family table as compared with dependence upon home gardens and home canning some years ago. She buys and serves her family canned foods the year around—even during the garden harvest periods. Her choices determine what products and how many cans are sold. She usually shops for foods from a moderate budget from which she must also supply some of her personal luxuries and movie tickets or toys for her children. Work by Krehl and Cowgill (12) on the "Comparative Cost and Availability of Canned, Glassed, Frozen and Fresh Fruits and Vegetables" for the years 1946, 1947 and 1948 in nineteen localities in the United States has shown that canned fruits and vegetables cost at least 50 percent less than the frozen and 15-35 percent less than the fresh. It is no exaggeration to state that the American housewife depends upon a large portion of her food buying from products packed in tin cans. Last year she set out tables with 1,000 kinds of food out of 30 billion cans—over 788 cans per family. To show that her confidence has not been misplaced, it is pleasing to note that canned food which cost $1.00 on the basis of 1935-39 prices in the United States, now costs $1.66, while the present index for all foods (canned foods included) is $2.32.

The American housewise demands value and quality and wants foods made by those who understand her problem of feeding and of maintaining the health of her family at a moderate cost. The canned food industry has accepted the responsibility of attaining the highest possible retention of nutrients in canned foods, and assuring those concerned with human diets, by sufficient data on the nutrient composition of canned foods, that they may be considered as nutritionally representative of the raw products from which they are prepared. The best guide to diet selection is still "The Basic Seven'" developed by the U. S. Department of Agriculture (2) during World War II as shown in *figure 1.* It will be noted that canned foods are shown or could be shown in almost all of the basic seven groups.



Courtesy U. S. Department of Agriculture

Fig. 1. The basic seven.

The year 1955, marks the fourteenth year of the National Canners Association—Can Manufacturers Institute Nutrition Program in behalf of the American canning industry and the consumers of canned foods. Prior to this program, as was highlighted at the National Nutrition Conference for Defense called by President Roosevelt in May 1941, there existed a need for more extensive and quantitative data on the nutritive aspects of canned foods, particularly for use by home economists, dieticians, members of the medical profession and other people engaged in diet planning or formulation, both for civilian and army purposes.

TECHNOLOGICAL PROGRESS RAPID SINCE TURN OF CENTURY

Since the early part of this century, technological progress in can manufacturing and canning and scientific progress in the field of nutrition have been rapid and most significant. From the canning of a limited number of food products in "hole and cap" cans by hand procedures in the early 1900's and a concept of nutrition then limited to proteins, fats, carbohydrates and minerals, we had progressed in 1941 to the high speed canning of a large number of food products in "open top" cans using automatic canning equipment and high speed closing machines, and to a concept of nutrition broadened to approximately forty specific nutrients, including the vitamins. The year 1941 marked the highest production of canned foods up to that time,

thus obviously showing that canned foods had assumed a very important role in the nutrition of the American people. There existed, however, in the minds of both the producers and consumers of canned foods a lack of knowledge about the vitamins, particularly with regard to their significance in canned foods. Some early reports had appeared which claimed canned foods to be devoid of the so-called vitamin B.

The studies of Kohman and Eddy sponsored by the National Canners Association over the period 1924-1937 had produced some information on the nutritive value of canned foods as determined mainly by animal assay methods and resulted in the publication of the original and revised Bulletins 19L (11) of the National Canners Association. With the fractionation of the originally known vitamin B into many well established entities and the development of methods for their determination, the need for further work on canned foods was clearly emphasized. It was fortunate that at the time of the inception of the NCA-CMI Nutrition Program, through basic research, some of which was sponsored by The Nutrition Foundation, Inc., many of the vitamins essential to human nutrition were known, and their properties, sources, human requirements, and convenient chemical and microbiological methods for their determination were being satisfactorily established. The "Minimum Daily Requirements of Specific Nutrients as Required by the Food and Drug Administration for the Labelling of Foods for Special Dietary Uses" was published in November 1941 (6). As a guide to improved health, the Food and Nutrition Board of the National Research Council issued in January 1943 recommended daily allowances for the various nutrients for men, women, and children. These were further revised in 1954 (7).

Two distinct objectives were outlined for the NCA-CMI Nutrition Program:

1. Determination of the specific influences or effects of commercial canning operations on the nutrients in raw canning stocks, the ultimate purpose being to improve retention of such nutrients in the final product.
2. Establishment of the nutritive values of foods canned by modern practices with respect to their content of vitamins, minerals, and the proximate food components such as carbohydrate, protein and fat.

One of the earliest decisions made was that, so far as possible, the greater part of the work should be done by qualified agencies not connected with the industry. This principle has, with minor exceptions, been followed throughout. What it meant at the outset was to enlist the interest of a number of colleges and universities outstanding for their competence in nutritional investigation, and arrange with them for the conduct of the various projects under research grants or grants-in-aid.

The following institutions contributed to this program:

- Cornell University (New York Agricultural Experiment Station)
- Michigan Agricultural Experiment Station
- Pennsylvania State College
- University of Arizona
- University of California, at Los Angeles
- University of Chicago
- University of Maryland
- University of Texas
- University of Wisconsin

In addition work was done by the laboratories of the National Canners Association and the American and Continental Can Companies. Forty-five original scientific contributions, a text book, and numerous other publications have provided a body of information on the nutritive values of canned foods probably more extensive than that on any class of food. The cost of this program to date has been aproximately $275,000.

The work on the nutritive composition of canned foods has been effectively summarized in the book "Canned Foods in Human Nutrition" published in 1950. On the basis of the collection and analysis of about 900 samples of commercially canned foods representing 42 different canned food products summary tables and charts were prepared which clearly provide a convenient and authoritative reference source on the nutritive values of canned foods, their proper handling and preparation for use by the consumer and their practical applications in meeting the optimum requirements of human nutrition.

Since this survey included analyses for proximate constituents, three minerals, and ten vitamins on over forty products, it is obviously possible here to touch only some of the high spots. The following are shown as typical of the types of data which are available:

- Approximate Calcium Content of Some Canned Foods (1, p. 102)
- Calcium, Phosphorus, and Iron Content of Some Canned Foods (1, pp. 215-8)
- Ascorbic Acid Content of Canned Foods (1, pp. 114-5)
- Carotene Content of Canned Foods (1, p. 122)
- Vitamin A and D Content of the Solid Portion of Selected Canned Fish (1, p. 225)
- Thiamine Content of Canned Foods (1, pp. 138-9)
- Percent Retention of Vitamins After Preparation for Serving (1, p. 187)
- Percent Recommended Intake of Essential Amino Acids Furnished by Average Servings of Various Canned Fish and Meat Products (1, p. 243)
- Nutritive Values of Average Size Servings of Canned Foods (1, pp. 241-2)

The N.C.A. Home Economics Division has prepared a loose leaf folder entitled "Canned Food Tables" (9) one side of which is a table of nutrients in terms of average size servings of fruits, juices, vegetables and fish, the other side giving servings per container and a wide range of products and container sizes. These tables have proved immensely popular; about four million copies have been distributed up to now.

QUANTITATIVE EFFECTS OF CANNING ON NUTRIENTS

The other objective of the NCA-CMI Nutrition program envisioned information on the quantitative effects of canning upon nutrients in common foods. A great deal of emphasis was placed upon this phase of the program in the more recent years. A bulletin has been prepared which will be published this year by the National Canners Association entitled "Nutrient Retention During Canning." In this bulletin will be presented data on the effects of various methods of handling raw products from the field to the point of canning, the effects of preparatory and canning operations and the effects of various storage conditions on nutrient content. Practices detrimental to nutrients are emphasized in favor of the best methods of operating cannery equipment.

The following titles are representative of the type of results of this work:

- Over-all ascorbic acid retentions (1, p. 111)
- Over-all carotene retentions (1, p. 121)
- Over-all thiamine retentions (1, p. 137)
- Over-all riboflavin retentions (1, p. 146)
- Ascorbic acid retentions during blanching (1, p. 110)
- Vitamin retentions in canned foods during warehouse storage (1, p. 177)

In 1935 the United States had slightly less than eight million people 65 years of age and over. By 1950, this age group had increased to more than 12 million. By 1960 the figure is expected to exceed 14.5 million, and by 1975 will total almost 20 million. This old-age group is expected to increase 156 percent between 1935 and 1975 as compared with 45 percent increase in the total population. These statistics are of vast importance in considering whether we have a need for a special class of foods beyond the wide variety of processed foods in our regular distribution channels today which might extend health, enjoyment of our life, and useful years for this important segment of our population.

Investigation of this subject in the food industry (4) has revealed that there is no established trend for foods for this specific usage outside of the increased use of low-sodium foods for high blood pressure and cardiovascular disturbances and the low-calorie foods for body weight control and use by diabetics. The latter are foods for the treatment or control of specific abnormalities.

Generally speaking, good nutrition and good diets for younger persons also meet the needs of the upper-age brackets, until some abnormalities manifest themselves. At all ages a good diet will help to avert these abnormalities and extend the useful years of life. A few years ago one had to be well-to-do in order to live on a restricted diet, but thanks to the efforts of the food industry, this is not the case today. Low-sodium and low-calorie foods are available for diet management of many of the abnormalities of the upper-age class. However, some consideration might be given to specially textured foods, packed in medium can sizes, to meet the physical and digestive food demands of many old people.

It has been brought to our attention that in St. Petersburg, Florida, (a haven for the aged) relatively large amounts of baby foods are sold in proportion to the baby population. Apparently a good many elderly persons are buying baby foods for their own consumption. But if these same baby foods were packaged in slightly larger cans and labelled "Geriatric Foods" or "Foods for the Aged," they probably would not sell as the old people would be embarrassed to be seen reaching for them in stores. Nevertheless, if the package had a descriptive label which clearly described the contents of the container and its specific usage, then we are sure that there would be a good market for these products. Pureed vegetables and fruits, in 303 can sizes would better meet the needs of the older person and at a saving over the smaller cans. Consideration might also be given to chopped foods and specially formulated stews.

At the present time there are few special foods being manufactured and designated for use by older people. Some dried milk products have been specially prepared and marketed as geriatric foods. Certain bread formulations supplemented with added protein have been prepared and used at the Elgin, Illinois, State Hospital. Low-sodium foods and low-calorie foods are designed mainly for the needs of those in the upper-age and old-age brackets. Formulated foods, specifically for this segment of our population, have not been ventured.

RELATIONSHIP OF FAT IN DIETS TO DEGENERATIVE DISEASES

The relationship of fat in our diets to the degenerative diseases is tremendously important in our consideration of geriatric foods. Ancel Keys reported some interesting work with respect to the diet and heart disease (10) and the relationship of concentrations of cholesterol in the blood to the development of heart diseases. It is suggested that our present plight with coronary disease is related to the fact that in the American diet, the

proportion of the total calories contributed by fats and oils has steadily risen since 1910 from around 30 percent to well over 40 percent. Contrast this with Italian diets which provide about 20 percent of their calories in the form of extractable fats and oils and Japan with less than 10 percent fat calories, where coronary heart disease is relatively rare.

The rise in fat consumption has taken the place of a corresponding amount of carbohydrates while the proportion of proteins in the diet has remained substantially constant. This brings up the question as to where we get the fats in our present high fat diet. Of our current fat intake, approximately 45 percent comes from cooking and salad fats and oils excluding butter or margarines. A little more than 20 percent comes from meats, fish and poultry, and little less than 20 percent comes from dairy products, excluding butter. About 4 percent comes from eggs, about 3 percent from butter, and the balance of 8 percent from cereals and grains, nuts, fruits, and vegetables. We should consider this list and the facts presented here. Obviously, the consumption of high quality foods should not be reduced, but the possible danger of a high fat diet for men in the thirties and beyond cannot be ignored. Here is a challenge not only for the men but even more for their wives, for the dietitians, and for the physicians upon whose advice they rely.

The production and marketing of dependable dietetic foods (3) represents an obligation assumed by the food industry in response to a demand of the medical and dietetic professions. From the practical point of view, we know that the demand for dietetic foods is large and that it will grow larger in the future. The life span is increasing and few people in the upper-age brackets can afford to be indifferent to the quality of the foods and beverages they consume.

The food manufacturer can be assured that not only does a demand for dietetic foods exist—a demand that will increase—but also that the production of dependable products affords business opportunities to small food concerns as well as to the large ones. In 1949, a census was taken of canners of dietetic canned foods and the products packed by them. The returns then showed 17 packers and 33 products. In 1951, there were 85 canners and 53 products with an estimated pack of 5,000,000 cases of canned dietetic foods for the year. A survey being conducted at this time, and as yet incomplete, shows 57 products in the low-sodium class alone, (the number of packers yet undetermined) and an estimated pack of low-sodium foods of well over 10,000,000 cases. There is a great trend toward water-packed fruits. One large packer produces only water-packed fruits, properly labeled for special dietetic use, and another large packer plans to pack a million cases of artificially sweetened canned fruits.

We feel confident that the food industry has the right philosophy on dietetic canned foods. The industry realizes that these special foods are used for feeding the sick or others who would not otherwise be in good health if their diets were not controlled. They also realize that there is an obligation on the part of the American food industry to see that the unfortunate are not exploited.

Dr. A. R. Colwell (5) claims that there is no absolute need for artificially sweetened foods for diabetics. They are a concession to the patient, in some instances, to provide psychological satisfaction. In this class are fruits, jellies, soft drinks and gelatin desserts packed with artificial sweeteners. Even though these artificial sweeteners are not harmful to diabetics, the medical profession recommends that the patient first be self-trained to like foods that are not sweetened. However, because of the harmlessness and definite psychological advantages, the medical profession is sanctioning the production and use of artificially sweetened foods.

Although the cost of using artificial sweeteners in canned fruits is no higher than with sugar, from the producers' standpoint, it costs more to produce these special dietetic foods for three reasons: (1) necessity for special production control and analysis; (2) smaller volume packs in many instances, and (3) special distribution. However, competition and the good old American system should bring these foods down to a price margin very slightly over that of conventional packs.

At an AMA conference on non-food additives, the question was raised as to "What should be done about the rest of the family when one member is on a special diet. Should they also be constricted to low-sodium or low-calorie diets?" This thinking has a great deal to do with package sizes and will tend to keep packages for special dietary foods in smaller sizes.

One of the great concerns of the canning industry was to get special dietetic canned foods out of the novelty or "racket" class. As a result we now see them in our regular grocery stores and that is where they should be. Since several states insist that dietetic foods be sold from one department, most chain stores now have a dietetic food section where more than one brand of low-sodium or low-calorie foods are shown.

The NCA-CMI Nutrition Program turned its attention to dietetic canned foods in early 1949. An extensive program was undertaken to establish the expected sodium contents of properly prepared low-sodium canned foods and to emphasize to canners the precautionary measures which must be taken in packing such foods, particularly since they are used in feeding sick people. This program was carried out in close cooperation with the American Medical Association and the

Food and Drug Administration. The information developed is summarized in the National Canners Association Bulletin "Dietetic Canned Foods" 1953. (1) In cooperation with the National Research Council assistance was given on the sodium content of a large number of processed foods for inclusion in their recent publication "Sodium Restricted Diets." (8)

SUMMARY

In summary you will recall in the beginning of this talk I mentioned that the American housewife has established her confidence in canned foods to meet the nutritional needs of her family. The work which has been reviewed for you here today I hope will justify the canning industries right to receive this recognition.

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Nutrition and Preservation Of Adult Health[1]

By Ancel Keys and Josef Brozek
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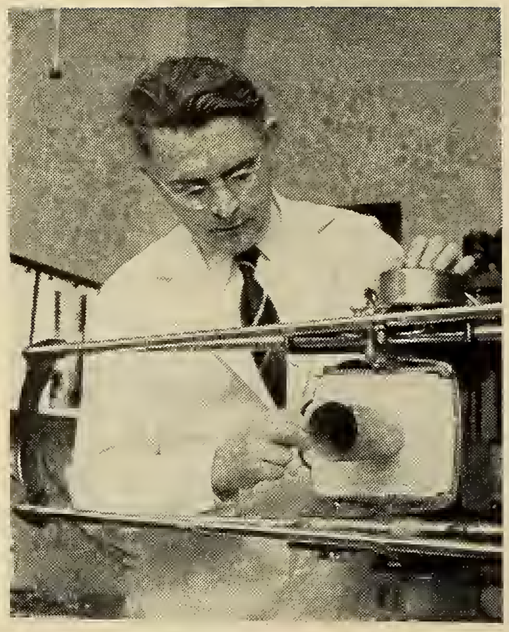


DR. JOSEF BROZEK, Associate Professor with the Laboratorv of Physiological Hygiene, School of Public Health, University of Minnesota. He was awarded a PhD. in 1937 at Charles University, Prague, Czechoslovakia.

IN CONSIDERING MATTERS OF HEALTH AND DISEASE from nutritional point of view, we face two distinct sets of problems: (1) The dietary management of the patient, particularly the chronically ill patient. In a few diseases such as diabetes and peptic ulcer the illness itself, or some of its manifestations, can be attacked by suitable dietary treatment. Far more often the task involves maintenance of the best possible state of nutrition in the face of the handicaps imposed by the illness. (2) The role of faulty nutrition in the development of disease and the efforts to improve, by dietary means, the health prognosis and longevity. This is a large and important area for research in which only the very beginnings have been made, if we disregard the classical deficiency diseases, such as beriberi or pellagra, which are totally unimportant as causes of death in the U. S.

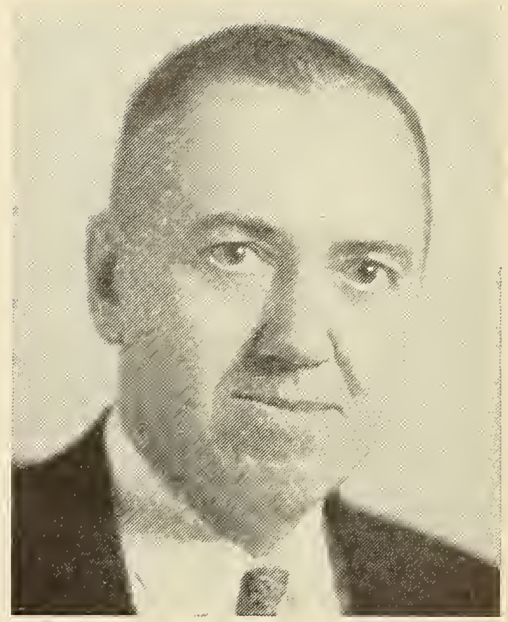
The crucial group are the non-infective, non-deficiency, chronic diseases. The list of these major causes of adult mortality is familiar. At the top of the list is the category of cardiovascular disease, not including disorders of the cerebral blood vessels, followed by cancer and other neoplasms, and then cerebro-vascular lesions. These three categories accounted in 1950 in the U. S. for 67 percent of all deaths of white men from age 30 to age 65 and for 72 percent of all deaths among women at these ages. Does nutrition have anything to do with the development of these diseases?

There is not the slightest evidence that either general or specific nutritional deficiencies promote the development of the diseases in this category. In the opposite direction, that is in regard to excess nutrition, there is evidence of a relationship and some hope for improving the situation by dietary means. The role of excess calories, resulting in obesity, and, in particular, of the fat intake will be examined on the basis of vital statistics, insurance data, field researches, and laboratory investigations.

[1]This is an abstract of the original paper that was presented.

Our Changing Food Supplies

By Oris V. Wells, Administrator
Agricultural Marketing Service



DR. O. V. WELLS, Administrator, Agricultural Marketing Service, U. S. Department of Agriculture in Washington. Dr. Wells was Chief of the Bureau of Agricultural Economics from 1946 until the organization of the Agricultural Marketing Service.

WITH AN ASSIGNMENT SUCH AS THIS it would be easy to drift into a sea of statistics.

For example, although we are today using (or at least causing to disappear at the retail level or its equivalent) close to the same per capita poundage of food as we did some forty-odd years ago, we are using some 220 pounds less potatoes and cereal products and some 160 pounds more milk, poultry products, the leafy green and yellow vegetables, tomatoes, and citrus fruit. Also, "red meat" consumption per capita has recently moved above the 1909-1913 level—about 128 pounds now compared with 121 pounds for the earlier date, after dipping to 103 pounds in 1935-39. Meanwhile, per capita use of sugar and sirups gradually increased from 88 pounds in 1909-1913 to 117 pounds in 1925-29, decreased sharply during World War II, and is now back to 107 pounds. As for fats and oils, butter consumption has been cut almost in half over the last 15 years, with an offsetting increase in consumption of oleomargarine and to a much lesser extent, salad oil (*see table 1*).[1]

Or, again, with an assignment such as this it would be easy to drift toward a more philosophical discussion of basic American food preferences as revealed by some of our more erudite methodologies.

For example, the 1925 discovery in New Mexico of the "Folsom point" (a primitive arrow or spearhead) intermingled with bison bones gives us a far more accurate index of prehistoric food preferences than it does as to whether the "Folsom man" ever actually existed or, if so, what he was otherwise like. And for comparative purposes, consider the findings of one of the most recent depth interview, market motivation studies: a study which summarizes the modern attitude toward meat by selecting and quoting the typical interviewee, "That's the chief difference in (grocery stores) —you find one that has good meats and you stay with it—grits, soaps, staples you can get in any store, but not meat."

Actually, I prefer neither of these approaches. Instead, I would like to consider the reasons why, in celebrating this hundredth anniversary of both Michigan State College and the beginning of our Land-Grant College system, we are discussing "Our Changing Food Supplies."

Why are we, at this particular juncture, interested in this particular subject?

I would assign the following as the major causes:

1. *Because changes in the character and qualities of our food supplies and diet offer great possibilities of better nutrition and better health.*

[1]Changes in food consumption for the years 1909 through 1954 are traced in detail in *Consumption of Food in the United States, 1909-52* (U. S. Dept. Agr. BAE, Agr. Handbook No. 62, Sept. 1953) and the Supplement thereto for 1953, carried in the July-September 1954 issue of *The National Food Situation* (issued quarterly by Agricultural Marketing Service). Statistical materials for earlier dates are more difficult to come by, but for a discussion of the American food picture of a century ago the reader is referred to Chapter III, Edgar W. Martin, *The Standard of Living in 1860,* The University of Chicago Press, Chicago, Illinois, 1942. Some of the best basic material dealing with changes in the consumption of cereals and related products from 1889 into 1923, during which period apparent consumption of cornmeal fell from 117 to 27 pounds per person and of wheat flour from 225 to 175 pounds per person, are found in Holbrook Working, *The Decline in Per Capita Consumption of Flour in the United States,* Wheat Studies of the Food Research Institute, Volume II, Number 8, Stanford University, California, July 1926; while some comparative material and interesting observations relating to food in the U. S. from 1789 to 1941 are found in Richard Osborn Cummings, *The American and His Food,* The University of Chicago Press, Chicago (Second Edition), 1941.

TABLE 1—U. S. civilian per capita consumption of food, by major groups, averages for 1909-13, 1925-29, 1935-39 and 1950-54[1] (Approximate retail weights)

Commodity	1909-13	1925-29	1935-39	1950-54	1954 preliminary
	pounds	*pounds*	*pounds*	*pounds*	*pounds*
Meat and game[2]	121	108	103	120	128
Fish[3]	11	12	11	11	11
Poultry[4]	17	16	16	27	29
Eggs	37	40	36	50	52
Dairy products:					
Product weight, excluding butter	374	375	376	413	415
Milk fat solids, including butter	29	31	31	28	27
Nonfat solids, including butter	36	38	40	47	47
Fats and oils, including butter[5]	59	65	64	66	65
Butter	17	18	17	9	9
Other	42	47	47	57	56
Dry beans, peas, and nuts	16	16	18	18	18
Potatoes and sweet potatoes	196	158	141	106	106
Tomatoes and citrus fruit[6]	60	71	96	108	111
Leafy, green, and yellow vegetables	62	97	106	103	104
Other vegetables and fruits	251	237	231	219	215
Sugar and sirups[7]	88	117	110	107	107
Flour and cereal products	287	234	201	162	157
Wheat flour	210	177	157	129	125
Cornmeal	49	29	23	12	12
Beverages[8]	10	13	16	17	16

[1]Retail weight represents weight of food as usually purchased in retail grocery stores. Ingredients of bakery products and other mixed food items are shown in their primary food groups.
[2]Excludes fat cuts of pork; includes offals.
[3]Edible weight.
[4]Ready-to-cook basis.
[5]Includes fat cuts of pork. Product weight except for oils used in salad dressing, mayonnaise, etc.
[6]Product weight except for concentrated citrus juices which are on a single strength basis.
[7]To avoid duplication, excludes sugar used in production of canned and frozen fruit, canned fruit juices, canned vegetables, unskimmed, sweetened condensed milk, and frozen dairy products except ice cream.
[8]Includes coffee on roasted basis, chocolate liquor equivalent of cocoa and chocolate products, and tea.

Some of our worst diet-deficiency diseases have either disappeared or been brought under control; nutrition is one of the most fascinating scientific fields, looked at either as a "pure" or "applied" science. Even our standard U.S.D.A. index of average per capita food consumption is essentially an index as to changes in the character and quality of the average American diet.

That is, when we say that per capita food consumption currently (for 1954 and in prospect for 1955) is running some 12 to 13 percent over 1935-39, what we are really saying is (a) that Americans are more nearly eating what they want than was the case as we moved to the end of the Great Depression and that, (b) thanks to nutritional research and education, Americans increasingly want a diet that not only supplies adequate energy (or calories, if you prefer), but more especially they want a diet that increases the average intake of the more-needed minerals and vitamins, with a strong leaning toward a high protein level (for a nutritional appraisal of changes since 1935-39, *see table 2*.)

A good start is not a sufficient basis for complacency. There is still more than enough bad nutrition and malnutrition in these United States. Such comparisons as are available between actual diets and dietary standards indicate that the nutrient most likely to be short in many American diets is calcium, followed by ascorbic acid and the B vitamins. Our farmers could go far toward making up these deficiencies if the food habits and the incomes of our consumers were such as to create the necessary demand.

2. *Because we like to eat and with a rising standard of living, basic or underlying food preferences can be more fully satisfied.*

The character and quality of a nation's diet is a function of (or depends in large measure upon) how well the general economic system is working. We have seen a gradual improvement in diets in the U. S. which has meant more than simply better nutrition. More and more families are *eating the kinds of food they like best,* but there are still many families where more and better food would be enjoyed.

There is a modifying factor to be considered. Today's housewife is interested—and I sometimes think the average husband even more so—in the convenience problem. Certainly, they want to meet their personal food preferences and to have meals with the proper nutritional content and balance, especially where children are concerned. However, most of us have neither hired cooks nor even general-purpose maids, so we increasingly want our food to come to us in forms that minimize work-time in the kitchen. So here we have a factor that conditions the *manner or way* in which food is moved to the consumer.

TABLE 2—Nutrients available for civilian consumption per capita per day, 1935-39 and 1947-49 averages, 1952, 1953, and preliminary estimates for 1954, with percentage comparisons[1]

Item	Unit	Average 1935-39	Average 1947-49	1952	1953	1954 preliminary	1954 as a percentage of		
							1935-39	1947-49	1953
Food energy......	Cal.	3,270	3,230	3,240	3,210	3,230	99	100	101
Protein..........	Gm.	90	94	96	95	96	107	102	101
Fat..............	Gm.	132	140	145	143	144	109	103	101
Carbohydrate.....	Gm.	440	406	398	396	397	90	98	100
Calcium..........	Gm.	.93	1.03	1.04	1.00	1.03	111	100	103
Iron.............	Mg.	14.4	17.0	16.8	17.0	17.0	118	100	100
Vitamin A value..	I.U.	8,200	8,300	7,800	7,900	8,000	98	96	101
Thiamine.........	Mg.	1.45	1.90	1.91	1.85	1.88	130	99	102
Riboflavin.......	Mg.	1.88	2.33	2.33	2.34	2.36	126	101	101
Niacin...........	Mg.	15.8	19.5	19.6	19.9	20.0	127	103	101
Folic acid.......	Mg.	.132	.133	.133	.134	.134	102	101	100
Ascorbic acid....	Mg.	118	121	114	116	116	98	96	100

[1]Data computed by Human Nutrition and Home Economics Research on the basis of estimates of apparent per capita consumption (retail basis), including estimates of produce of rural and urban home gardens, supplied by the Division of Agricultural Economics, AMS. No deduction has been made in nutrient estimates for loss or waste of food in the home or for destruction or loss of nutrients during the preparation of food. Data for iron, thiamine, riboflavin, and niacin include the amounts of those nutrients added to prepared cereals, white flour and bread.

3. *Because we believe that changes in the character and quality of the American diet offer the most sensible solution to some of our pressing farm surplus problems.*

This point has been stated many times, in many ways, by nutritional scientists, agricultural economists, and farm organization leaders and Secretaries of Agriculture, past and present.

A continuing shift in diets toward the protective fruits and vegetables promises a more attractive market to many of our specialized intensive farming areas; and a shift toward milk, eggs and meat promises more attractive markets to our general farming areas. Production of animal products employs more farm resources per consumer than would be the case with a more nearly cereal diet and in our expanding high level economy gives better returns than straight grain farming. At the same time, both shifts mean better diets, better nutrition, and better health to consumers generally; more business and the chance for greater operating efficiencies to all the food handling industries (since volume and efficiency are so nearly synonymous in our mechanized society); and far fewer problems and administrative difficulties for our legislators and Government officials, State and Federal.[2]

Now let me say that we should not necessarily accept the above line of reasoning uncritically. Some economists have called attention to the relatively low income elasticity of food expenditures in our economy, while the elasticity of demand for increased services (trimming, freezing, packaging, etc.) appears in many cases much greater than it is for the basic food component itself. But nevertheless this is the line of reasoning that underlies many of the basic decisions in the food and farm policy field. That is, we are increasingly inclined to take the view that a shift toward better diets, including a shift toward a grassland or livestock type of agriculture, can go a long way toward solving some of our basic agricultural difficulties. At the same time, we also need a continuous and more conscious analysis

[2]Suggesting a shift in American diets toward the protective vegetable and livestock foods represents a complete reversal from some earlier views.

According to Cummings (*The American and His Food*), W. O. Atwater, the first of our nutritional experts, believed that "he who would live wisely and economically could have some meat . . . but would fill out his calorie allowance with some cheap food, such as bread, and avoid leafy vegetables. . . ." Taking what he believed to be a broad view of the food problem, he pointed out that international competition in industry and commerce was becoming stronger and population was growing denser. As a result, he believed that unless American workingmen reformed their diet by greater use of energy-yielders, the future would bring loss instead of gain in material prosperity, and a 'fearful falling away' rather than an improvement in morals would occur. Editors accepted Atwater's conclusions at face value, and the *New York Times* called on the clergymen of the cities to inform their congregations as to means of economizing."

O. E. Baker was much concerned with this same Malthusian worry until the advent of farm surpluses shortly following World War I. Meanwhile, as late as 1936, R. M. Salter, R. D. Lewis, and J. A. Slipher in Extension Bulletin 175, Ohio State University, indicated that many improved farm practices had been at least partially adopted over the 50 preceding years but that "The natural productive capacity of the land has been deteriorating at a rate almost fast enough to offset all of these improvements in soil and crop management. . . . With every step ahead we have slipped back almost if not quite as far." In short, modern science was doing well to offset the increasing incidence of viruses and insect afflictions and more especially the "vicious" force of soil erosion.

Dr. Byron T. Shaw, Administrator of the U.S.D.A. Agricultural Research Service, has more recently endeavored to reconcile these earlier concerns with current beliefs. That is, in various statements, especially in appearances before the Congressional appropriations committees, Dr. Shaw views the current situation as one of relatively plentiful supplies but insists that adequate future supplies for an increasing population can only be assured by expanding agricultural research programs, with increasing emphasis on basic research.

of this problem than has been given at some times in the past.[3]

What are the specific devices and broad general policies that will move American diets and American agriculture in the direction our discussion has implied? And returning to the fact that we are celebrating the hundredth anniversary of a great research institution: What are the problems in this field that need increased research attention?

From the standpoint of research, we must remember that nutrition is a relatively new, fast expanding science. There is much we still do not know but other papers deal with the nutritional fields that need to be further explored. The questions that I want to leave with you fall within the marketing field.

We still know too little about food preferences, habits, and the other forces that influence or determine the *economic demand* for food under differing circumstances. This is especially true in our present-day society, where the consumer does not buy food alone but a "package" or combination of food and services in which the services account for at least half (or, using one of our more widely known average indices, currently 57 percent) of the retail cost.

Policy-wise, I know it is often argued that marketing activities, both private and public, should be restricted to two fields: that the function of the market system is (a) to serve as a neutral purveyor of goods that the consumer may want, and (b) to make a livelihood for the workers and a profit for the businessmen involved, with returns or profits regulated by competition.

American businessmen, however, have never been willing to meekly serve merely as neutral or static purveyors of goods and services. Rather, they have endeavored to create new demands, to build new markets—some of them spectacularly so. One of the more successful of these enterprisers suggests that success in the particular case was due to "bold gambles on the use of new machinery and the fresh use of the printed word." Or, if you prefer the modern idiom, automation and advertising (although it seems to me both terms are much too narrow to cover all the complex processes involved). And this continual American drive for new or expanding per capita markets is one of the essential mainstays of the "expanding economy" about which we all talk so much.

I am not arguing that salesmanship alone will do the job. We are interested in efficient production and efficient marketing, in lowering costs, in improving quality, and in reducing waste. Good progress has been and is being made on the farm production front and we are at least beginning to work on problems of marketing costs and efficiency, much along the lines that have worked so well in the production field.

Nevertheless, research-wise, we have paid far too little attention to the whole problem of creating or maintaining demand. This is an urgent problem. It is urgent because American farmers and food processing industries are making some significant attempts to do something about it. It is urgent because our beliefs in this field, however good or bad they may be, must influence many major policy decisions relating to farm support prices and farm surpluses, either actual or potential. And it is urgent because our high dietary level in the U. S. is not automatically destined to increase further but could in fact be deflated under certain circumstances, if we make the wrong decisions based on inadequate knowledge.

Fortunately, this is a field in which there seems to be a new, reawakening interest. Various studies and activities are going forward in the U.S.D.A. which we hope will give some leads to a better understanding of the nature or structure of the demand for food. You have a most interesting food panel project under way here at Michigan State College. And various private interests are also endeavoring to obtain a better scientific approach to their problems, as witness the increasing use of commercial market research. Meanwhile, the most encouraging sign of all is the fact that farmers and the food handling industries are increasingly interested in this whole field, that they are actually at work trying to find ways of getting along with the job.

[3]For a good statement and provocative discussion of one of the basic questions in this field—the question as to whether there is a difference between the short-run and long-run elasticities of the demand for meat and other foods—see: Elmer J. Working, *Demand for Meat,* Institute of Meat Packing, University of Chicago Press, Chicago, 1954.

Symposium Discussion Sessions

Monday Morning

Colonel P. E. Howe: What were the effects of the two sets of crops on the appetites of the animals? Often the appetite of the animals is affected.

Dr. Dexter: This question should really be referred to the dairy man on our team, but I can say that the coarser fertilized hay was eaten much less freely than was the finer unfertilized hay. There was no difference that could be seen in the case of the grains.

Question: Was the drinking water analyzed?

Prof. Duncan: Yes, several such analyses were made.

Question: Were the meteorological relationships of composition studied?

Dr. Dexter: No, but complete weather records are available from a weather station a mile away, and this could be done.

Col. Howe: Was the botanical composition of the crops from the two areas the same?

Dr. Dexter: We expected trouble with clover in the fertilized hay, but actually had none. The use of nitrogen fertilizer and the long time since clover was grown on the farm were no doubt both helpful. At first there may have been a little more Canada bluegrass and a few more weeds, largely sheep sorrel in the unfertilized hay. Otherwise, the composition, botanically, was much the same. On the grain fields, of course, we harvested very much what we planted.

Monday Afternoon

Dr. R. W. Lewis: Talking about these requirements of plants, how do these modern notions stack up against the Liebig's Law of the Minimum and Blackman's Law of Limiting Factors?

Dr. A. G. Norman: The question was, "How do these notions of requirement stack up against the Liebig's Law of the Minimum and Blackman's Law of Limiting Factors?" I do not think there is a serious variance with them. While the Liebig's Law was somewhat simplified, it probably was operative at the low end of the different levels of which I spoke; namely, the minimum requirement is what would be involved there. In the zone called poverty adjustment that I mentioned, there is an increase in growth, and increase in yield in respect to the addition of the nutrient; then there is one that reaches the zone of luxury consumption, an adequate supply. At this point there is no longer a growth increment for the added nutrient. I think the chief difference is that we recognize the interactions between the nutrient levels in a way that was not recognized in these rather simplified laws when they were first elaborated.

Dr. J. E. Grafius: How do you explain the differences in rate of growth between different genotypes if the net assimilation rate is almost constant?

Dr. Norman: If I gave the impression that I thought that the net assimilation rate was a constant, I was in error. What I intended to say was that it was not constant, but it was not greatly affected by environmental factors. Unhappily, there have not been nearly enough studies in this field that we might call crop physiology—the kind of thing that would enable us to answer the question that Dr. Grafius asked. To my knowledge no one has really compared a number of varieties at the same location. There have been, perhaps, two varieties or something of that sort, but the same varieties have not been compared in different locations. What I tried to imply was that from the limited evidences that we have, it seems that the net assimilation rate does not vary greatly. However, the other components, namely leaf area and duration do vary greatly. I am inclined to believe that this is even more important—duration of maintenance of the leaves in their most active photosynthetic condition.

Dr. R. L. Carolus: What was the reason for timothy responding to fertilizers and the other crops not responding to fertilizers?

Prof. Duncan: I have not any very sound answer to that question except that I understand that the timothy is a different feeding plant than the other crops. The other crops are apparently deeply rooted. Their roots go down farther into the soil. There is more root surface exposed to the soil in the corn, in the soybeans, and in the brome, than in timothy. The timothy is apparently a shallow rooting crop and, therefore, it would respond to fertilization more than the other crops.

Col. Howe: What is the relation between the roots, the leaves, the stems, and the heads of the two lots of timothy?

Prof. Duncan: We did not make any particular study of those three factors because the timothy hay was cut for cattle feeding purposes. The timothy grown

on the fertilized soil was cut first because it matured faster and contained a little more crude fiber. The unfertilized timothy hay was shorter and we allowed that to grow a little bit longer. Neither leaves nor heads were analyzed separately. The timothy hay that was grown on the unfertilized soil was shorter and finer, and at the same time it contained less of the organic and mineral constituents than that grown on the fertilized soils. The plant itself responded differently.

DR. W. B. DREW: Would you comment on the apparent effect of climatic factors on the different protein content of the soybeans in the different years?

DR. NORMAN: This may well be, in part, an effect due to the leaf situation in soybean plants in those particular years. For example, a dry spell may have made for early abscission of the lower leaves, and consequently not as much protein was mobilized and moved to the grain as in another year. On speculating, I do not know what the weather conditions were in those particular years, but some sort of change of that type might well be responsibile for the different protein levels of those two years.

DR. DEXTER: All the soybean crops were remarkably poor. There was very little difference in the yield in the soybeans whether they were fertilized or not. In fact, year in and year out I would say that the unfertilized soybeans did better than the fertilized. The difference was mainly a problem of weed competition. The weeds did very nicely on the area that was fertilized; but, unfortunately, the soybeans did not react as favorably. This is definitely not soybean land. Now, whether or not the weeds were unusually bad in these particular years, I am not sure, but I can say that the soybeans on both areas were remarkably low in yield.

DR. COOK: I would just like to point out that in the greenhouse we got our greatest difference in composition in the case of the soybean crop, but in the field, timothy demonstrated the greatest difference in composition. Those are two crops which ordinarily, in our common fertilizer work over the State,—and I think the same thing, in respect to soybeans, holds true in our neighboring states to the south where they grow so many soybeans,—do not give much response to fertilizer. It just seems to me that it might mean a little something that we have two plants here that do not respond with increased yields to the fertilizer application. Therefore, if they are not being increased in growth very much, as a result of fertilizer treatments, the composition of the plants is more likely to change.

DR. SAUCHELLI: Is it possible that the timothy outran its nitrogen supply more than the other crops and was really in the nitrogen deficient range, which might explain the accumulation of the other minerals more than in the other crops?

PROF. DUNCAN: There is a possibility that that is what happened. You noticed from the tables that the timothy hay was grown in later years than the brome grass. Both the brome grass and the timothy hay received an application of nitrogen, but the mineral supply in the soil or the available minerals in the soil after the brome had been grown for 4 years may have been reduced to a lower extent. That is a possibility for explaining the behavior of timothy.

DR. DEXTER: Since we applied the same amount of nitrogen per acre on the fertilized as on the unfertilized soil, the unfertilized area had, comparatively speaking, a high nitrogen supply. It is somewhat contradictory that timothy on the unfertilized area should be lower in protein than the timothy on the fertilized area. I really would have expected the reverse. In other words the timothy on the unfertilized area certainly did not seem to utilize the nitrogen that was available to it; it was really rather heavily fertilized with nitrogen for what hay we got.

DR. R. E. MARSHALL: Are you satisfied with that explanation?

DR. SAUCHELLI: I'm more confused now than ever. Would it be a fair question to ask if you really had a balanced nutrient status in the soil on the fertilized area?

DR. COOK: I am inclined to think that we did have it fairly well balanced. There was never a high test indicated in the soil even though we put on a lot of fertilizer. In fact, we increased the potassium content in the soil only from about 60 to 70 pounds per acre up to 90 to 100 pounds per acre by all fertilizer applied. Now it is a hard job to sample 10-acre fields and come up with some results that would stand statistical analysis. I think that if we analyzed the data statistically, we would find that we did not actually change, to any great extent, the nutrient content of the soil as measured by our soil tests. So we never did have real high mineral nutrition in those soils. So, if the nitrogen did run out toward the end of the growing season of the timothy, I think that probably it was a good idea to maintain the balance because we were not high on minerals. But, all in all, from the appearance of the plants, we never did get very marked deficiency symptoms showing up on the fertilized or unfertilized areas. We never saw any starvation signs, and we have been studying starvation signs and feel that we can tell

when we see them; they just were not there. I think this is one of the best indications that we did have fairly good balance because it is when we have unbalanced conditions that we have starvation signs showing up. It never did show. I do not think we have very serious nitrogen starvation at any time.

MRS. KOFFLER: Did you have nitrogen fertilization in all periods on the so-called unfertilized areas in the same amount as on the fertilized?

DR. DEXTER: The amount of nitrogen put on per acre was the same whether mineral fertilizer was used or not. In other words, an acre of grass hay receiving 60 pounds of nitrogen received 60 pounds of nitrogen whether or not it received phosphorus and potash.

MRS. KOFFLER: Did you always harvest later on the unfertilized areas?

DR. DEXTER: No, we did not. In the case of grass hay, the grass hays that were fertilized with mineral fertilizer were always more advanced in blooming, or heading out on the fertilized areas than on the unfertilized; consequently, we cut them first, allowing the unfertilized to grow whatever time was necessary. However, with the other crops, they were all harvested very much at the same time although with a 200-acre farm you cannot harvest them identically. In the case of the soybeans, no nitrogen was used on either crop.

MRS. KOFFLER: How much later were the hays harvested on the unfertilized areas?

DR. DEXTER: In a general way, I would say a week later, a week or ten days, in that order of magnitude. This, by the way, may partly account for the fact that the fertilized timothy hay was slightly higher in protein since it was harvested perhaps a little earlier, physiologically speaking.

DR. ZOE ANDERSON: It might help if you would clarify why the nitrogen was used on the unfertilized plots.

DR. DEXTER: It was used for a very practical purpose. The hay without nitrogen fertilizer was so short (6 inches) that when we mowed it, we might as well have been running the mower down the road; when we ran the rake over it, the hay went between the teeth. In order to get a little growth then, we used nitrogen fertilizer on the grass crops, similarly, with the wheat, the oats and finally the corn.

DR. MARSHALL: If there are no further questions we will get back to the Kellogg Farm Nutrition Experiment which was so well introduced this morning by Dr. Dexter. We have had some personnel changes in the past 10 years. Before I introduce the next speaker I want to introduce the man who was chairman of this project for the first 5 years of its existence. Dr. C. E. Millar (please stand). He is Professor Emeritus of the Soils Science Department.

DR. H. B. TUKEY: I don't have a question but I would like to make a few comments. We have been talking so far about plants that are derived from seeds in which the tops and roots are identical genetically. I scarcely know whether this is environment or not. But when we put together, as we do in our fruit trees, a scion variety on a root stock, the root stock becomes a factor in the environment and the effect is profound. We take a variety of tree like the MacIntosh apple with a 50-foot spread and we graft it on to a suitable root stock and it may have a 10-foot spread. We may have a case where varieties of fruits that are not adapted to regions of the country will survive in one region and not in another. We have a case where the sugar-to-acid ratio in citrus is profoundly effected by the root stock, and there are some other remarkable cases. I don't know whether this is a matter of genetic relations; I scarcely know whether they are genetic or environmental. The last observation is this and it may not be appropriate at all. When I was sitting here I could not help thinking about these people and how prolific they have been and the number of papers they have presented. I would like to remark that no one up to now has made a remark about the nutrition of the speakers and their production of papers. I would like to suggest we refer to Shakespeare and his comments in regard to Cassius and this seems to be, as I look at this group, appropriate,—"this lean and hungry look."

MR. OLLIE FINK: I was a little disappointed that the graphs which were used in this presentation were on the absolute basis. It seems to me that it would be more effective if we considered the percentage difference between treatments rather than the absolute differences as such. For example, if the percentage of protein is 9 percent in one case and 10 percent in the next, the difference between them is 10 percent relatively while only 1 percent in the absolute figure. Or in a graph showing this difference, 3 percent and 4 percent, the difference is not 1 but 25 percent. I think it might be appropriate for all of us to keep in mind that when we are dealing with some percentages of proteins in the animal experiments here the 1 percent is a significant difference. I would like to bring my point up for your reflection.

DR. NORMAN: All I would say is that it is a very valid comment to make. It is a little misleading when we look at tables of this sort where different constituents are present in vastly different amounts. One of the elements may be there in

0.002 percent or something of that sort, and the relatively small change can be quite important and meaningful. It is not quite in the same category as a component that is present—say 25 or 30 percent. No, your point is entirely valid.

DR. MARSHALL adjourned the meeting.

Tuesday Afternoon

DEAN MARIE DYE: Is there anyone who would like to lead off with a question about this interesting subject of the past and present in human nutrition?

DR. ZOE ANDERSON: I am sorry but it was so beautifully done that we have nothing to say but thank you.

DEAN DYE: Thank you, that was a very nice comment. Any other comments to make about this discussion which we just heard?

DR. J. MEITES: I am interested to know why no reference was made to endocrinology or endocrine relationships in nutrition.

DR. NEIGE TODHUNTER: That is very easily answered. I did that paper with my eye on this watch at all times. There were endless things that were left out as you all well recognize—that of endocrinology is one of the new and exciting phases. We have very little real knowledge of how nutrition fits in there, but it is one of the new areas that is now advancing rather rapidly and we hope will have some good things that we can pin to in the near future. Many people have and are now carrying on studies with relation to the vitamins, to the relation of stress and nutrition, and many inter-relations and crisscrosses and that whole pattern. But I have the only possible answer to that, and that is time, which had to eliminate so many things. It was a matter of picking out a few high spots that seem significant to the person presenting the paper, which does not mean that they are necessarily significant in the history of nutrition.

DR. L. M. TURK: What is our number 1 nutrition problem in the United States?

DR. TODHUNTER: The classic answer as given by the medical men, the biochemists, and a good many nutritionists is obesity. My answer is lack of information about nutrition. Our greatest problem today is nutrition education for the people. I have other people who would say otherwise, but that is my answer to your question in giving you the generally accepted one also.

DR. MEITES: How generally is vitamin content of foods a critical factor in diets?

DR. TODHUNTER: With regard to the vitamins, not that they are not necessary, but for the normal individual, a wise selection of food, or food selected on the basis of nutrition knowledge, which we would like everybody to have, makes it possible to meet the normal requirements. I keep emphasizing normal because when you are off-normal then you are into another field entirely—with due recognition of what enrichment of bread and flour has done for certain groups, the addition of vitamin A to margarine and what that has done to the particular part of the country where I come from where economic factors do not make it possible to meet the price of butter—the natural food supply can meet the vitamin needs of the normal individuals. If we get into unwise, additional use of vitamins directly or the indiscriminate fortification of other foods we are going to be in serious difficulties and without any contribution to the improvement of the health of people.

DR. K. T. PAYNE: Are there some legumes that are better than others in providing these proteins?

DR. DARBY: There are some that are better for certain regions. Some of our legumes will not grow under the environmental conditions that one encounters in the area where they are most needed.

DR. MEITES: In some foods—rutabagas among them—substances are found that are very potent in favoring the production of goiter. Do you know of any cases in your travels, where such regions exist, where goiter is common, and yet where iodine in the diet appears to be adequate otherwise?

DR. DARBY: I don't think we know the relationship of the goitrogenic substances in the diet to human goiter at this time. One finds in many sections where careful studies have been made, a good inverse relationship between iodine content of soils, water and vegetables, and the occurrence of endemic goiter. Secondly, one can prevent and cause a remission of early goiter by giving iodine. Finally, we have the experience there where effective programs of iodination have been possible at a level as high as we have used that goiter has pretty well disappeared. So whether or not the goitrogenic factors are important, I think will be more or less academic in so far as practical programs are concerned, because thus far at least, all of the evidence is that an effective procedure is to give iodine. It may be, as we learn more of the response of areas of endemic goiter, that we may find some areas where the goiter is not responsive to iodine or cannot be prevented by iodine. In those situations, one may find that it is related to some goitrogenic agent either in the water or in some of the common food stuff such as rutabagas and so forth. I know of no such good evidence at this time; however, so this rather long answer to your question is no.

PANEL DISCUSSION

Wednesday Morning

MRS. SMITH: Most of the speakers here, in fact all speakers on this panel, had an opportunity to express their gratitude and appreciation for the privilege and opportunity to participate in this first of the ten Symposia as part of the Michigan State College centennial celebration. I am going to add my appreciation to theirs, and I am sure the audience feels the same way. It is a real privilege and treat to be able to participate in this type of meeting.

When thinking about how we might open such a panel as this I was impressed yesterday by Dr. Todhunter's presentation of the growth and development of the science of nutrition. I could not help thinking how similar it is to the growth and development of human beings. I won't try to check the analogy from the marriage ceremony through every step to our present concern about old age, but there are some points of similarity that I might mention.

She talked first about the marriage of physiology and chemistry to help us create the science of nutrition. She told us as she went along some of the peaks and plateaus that we have had which is just what we see when people are growing. We have seen some of the "growing pains" which are evident in human beings as well as in some of the sciences and particularly in the science of nutrition. She pointed out to us that some of the things we learn, we learn by trial and error. She pointed out that some things we learn in a more sophisticated manner. I was impressed too with what happens to the things we learn in this modern society. We are living in an America where there seems to be a premium on speed. When many of us were learning science in our undergraduate days, we were impressed with the fact, and were told, that it took about 15 years from the time the scientist gave us a finding until it was applied by the general public. There are some cases where that 15 years has become 15 hours. Unfortunately, there are some cases where that has become 15 times 10 years before it actually registers and is applied. There may be some advantage in this speed, but it is not without its hazards because with speed we sometimes lose accuracy. I think that has happened somewhat in the field of science. We, in our speed, have become headline readers, too. It is dangerous to take a scientific finding, read the headline without reading the facts, and then let that become a part of arriving at a conclusion. We have grown, however, to the point of sophistication and perhaps I should say to the stage where we philosophize, too. We have seen some of that throughout this 2½ day conference. I was impressed, too with the fact that this symposium has illustrated one of the other points that Dr. Todhunter mentioned and that was that the growth and development of the science of nutrition has made it possible to become team workers; we have such a team right here today. I would like to introduce Dr. Wells, Dr. Clifcorn, Dr. Brozek, Dr. Norman, Dr. Albrecht, and Dr. Beeson.

We have had some 15 or more participants in these 2½ days. We started logically with the soils and plants and proceeded to the animals and human beings. I think we might well do that very thing with our panel this morning. Before I call on panel members I would like to say just one other thing. When any group of people interested in nutrition in this country gets together to talk about nutrition there are two pieces of work that inevitably enter into the conversation: (1) The research that has been going on at Michigan State that we have been hearing about. We have heard smatterings about it—at least some of us that are near enough to Lansing have—but this is the first time that we have had a really comprehensive look into the findings of that project. (2) We also hear in any discussion of nutrition of the work that Dr. Albrecht has been doing. Now we thought that perhaps this morning we might ask our two panel members who have been vitally concerned with plants and soils to start some of this discussion. I am asking you to do this because you have not been directly involved in either one of the above mentioned projects. So I wonder if Dr. Beeson would like to comment first and perhaps, while he has the microphone, he might like to answer a question that has been directed to him.

DR. BEESON: First of all I would like to commend the staff at Michigan State College who have carried on this very fine cooperative project. It has been only in the last generation that such cooperative projects have been possible. They still are few in number. Hence, I think this is an achievement in itself that they have been able to carry on over such a long period of years such a large cooperative project. I am sure that the data that investigators have accumulated are going to be studied for more years that it has taken to obtain them. We are going to refer to this project for a long time. I think that we are going to find the more we study these data, the more we get out of them. It is almost impossible within the 2-day period, of course, to really appreciate the value of the findings that have been given to us during this symposium.

There are many ways, in my opinion, of testing soil fertility. I am sure that the workers here at Michigan State College would be the first to agree

that the particular tests that they have made are not the only ways of testing soil fertility. As a matter of fact, I believe they would agree that the cow is probably not the most sensitive animal for testing soil fertility. Certainly the cow will not discover those subtle differences in soil that some day we may find to be really important in terms of human nutrition. Then what is the great value of this experiment? In my opinion it is that they have again shown that the composition of this food, milk, recognized to be one of our best foods, certainly one of our best foods for children and even for adults, is reasonably constant regardless of the nature of the food. If this food can be produced we can do more to improve the nutrition of people in areas of very low soil fertility than possibly any other thing that we can do, directly or indirectly, and quickly. Hence, it is extremely important that we know how to produce enough feed for a cow in some of these areas.

I am very much interested in the things that Dr. Albrecht has reported because his basic experiments with calcium in the soil show us how we can take some of these poor soils and produce the kind of feed and foods that we need. In other words, the important thing in this particular experiment is that we have been shown how we can make a choice of crops. Not that we improve something directly for human nutrition, but we can choose the kind of animal crops that we want to produce in order to provide the maximum help for some of our people in areas where, for example, milk has been almost a luxury. I think that is one of the important things to get out of this discussion during the past two days.

I have been given this question: Have you found a generally high nitrogen content in non-legume plants that were supplied with high calcium nutrient solutions, nitrogen remaining constant?

I cannot answer that question directly from my own experience. I am quite sure in cases of critical calcium deficiency with an increase in the calcium supply one might increase the absorption of nitrate nitrogen, but I cannot recall an experiment to back up that statement. May I refer it to someone else?

Mrs. Smith: Is there anyone else who would like to speak on that question either on the panel or in the audience who has some evidence to present? If not, I would like to call on Dr. Norman as our other expert. I don't really like the word expert but I guess that is the most accurate term of reference.

Dr. Norman: I have a colleague who has a habit of deflating a speaker who is sitting down with a glow of accomplishment by saying, "Well, that is all very well, but what is the take-home lesson?" I suppose we are really here to consider the take-home lesson. We have had painted a large canvas, and I would imagine that there are many take-home lessons. In our respective fields and with our respective interests, we may not all take home the same lessons. At the risk of making what might sound to be another talk, I would like to try to list what I think to be my take-home lessons, and I do this primarily with consideration of the earlier part of the program.

First, I hold it to be proved that there are interrelationships and interdependencies between the nutrition of plants, animals and man, and that some of these stem back to the soil and soil fertility.

Second, as a matter of logic, I hold that things that are related and validly related are not necessarily always causally related, and that this applies to the conclusions in the previous sentence. The establishment of a causal relationship may be something that requires much more rigorous testing. The obvious explanation of an experimental result may not always be the right one. A plausible explanation still needs rigorous testing. We have before us, I think, in this fascinating nutrition experiment, the kind of rigorous testing that has to be applied to those explanations that may seem plausible but not necessarily proved because they are plausible.

Third, I hold it *not* to be proved that all nutritional disorders stem from soil deficiencies or lack of proper management or misuse of land. I hold it *not* to be proved that through soil manipulation inadequacies in composition of crops as dietary ingredients for animals or man can be corrected, or indeed that this is necessarily the best approach to correction of dietary deficiencies. I am not at all willing to accept the view that nature knows best. I am very distressed when I hear scientists use the word nature with a capital "N" in their explanations and discussions. There are many examples, that all of us would have no difficulty in putting our finger on, where nature does not know best; so I regard this as a completely unacceptable debating argument.

I sensed some kind of feeling of conflict yesterday—some sort of feeling of inadequacy in the data relating to the nutrition experiment—some feeling that there must be a kind of flaw in the design or in the analysis or the conduct of the experiment. The questioning at one time seemed almost to put the Michigan State workers on the defensive. Now I think this was not the real situation at all. These problems are not being investigated to prove a hypothesis. The apparent conflict arose because it seemed that they had been so undertaken. Experiments are undertaken

to test a hypothesis, and that was, in fact, what was going on.

Finally I hold it to be established that, in these experiments, the quality of milk and the well-being of dairy cows was substantially *unaffected* by the fertilizer treatments applied to the land that was used. However, we cannot extrapolate from this and say that soils and nutrition are unrelated. This would be a completely unscientific and illogical prediction. Whether or not they are in a particular circumstance can only be tested by the kind of meticulous experimentation that was reported to us.

MRS. SMITH: I think that you are going to hear your term "mischievous nonsense" quoted more than once in the state of Michigan, perhaps in other places because of the very expression, the very words, may I say. It brought to mind something else that distresses many of us who are working in the field, and that is the fact that it is so easy for the uninformed to say, "You put nutritional elements into the soil, the soil puts them into the plant, the plant puts them into the animal and into man and it's just like that." Unfortunately we have been taught that way in our public schools, and in some of our lay groups. So that I think this group of scientists who have come here, will help us to "think critically," as Dr. Todhunter said. We get scientists with imagination and ability to observe keenly, and I am sure Dr. Albrecht told us yesterday how important it is to think critically and at the same time to be stimulated. Dr. Albrecht, would you like to have a word particularly to the questions related to the plant part of this panel?

DR. ALBRECHT: The matter of stimulative thinking is a problem in our educational procedure which, in my opinion, we have neglected. We may illustrate with a child. When we get tired of answering questions, we put the child into the schoolroom and instead of answering his questions, we set him to memorizing the things we think he ought to have. So I am interested in this approach to the problem of agriculture which is really a problem of learning more about how we can use some of the natural performances that are to feed us.

The breakdown of rock in the soil is that natural performance. We have some soils in which there is very little rock breaking down; they have only what is in reserve on the clay. If you study the pattern of the United States, it is in the mid-continent where we have the reserve minerals breaking down. That is where we are finding our high output per acre and per farm. We go to the West and we have the salts as fertility—poor combinations— but not the water. We need the chemodynamics of ionic activities in the soil to feed the crop. In the West we have plenty of salts that can be ions but they are in the dry soil.

Northern Michigan is a wood-producing territory, and that duplicates a good deal of the eastern United States where the woods are coniferous wood with not even seed producing trees. They are on the fungus level, i.e., spore-producing. There we do not have soil dynamics that will support the highly complex animal or even the human. In eastern United States we have lots of water but not enough ionics or chemical dynamics. This larger pattern of agricultural production according to soil dynamics is basic, in my humble opinion.

When we move about on the face of the earth we ought to start our thinking about agricultural possibilities with some of those ecological manifestations. I feel we have not seen or appreciated what is required in the soil, as chemical dynamics, to give us plant dynamics, animal dynamics and, as Dr. Todhunter emphasized so nicely, "all that it takes to have human body dynamics." With that as an illustration, I would like to have us feel that we need some stimulative thinking according to the soil fertility pattern.

As a relatively young man visiting the British museum and waiting for the rest of our group to get together, I turned to the famous manuscript room and saw some of the correspondence by Darwin. Some of the ministers of his day did not like what he said about evolution, especially that man may have, at some time, resembled the monkey. Darwin said, in putting out this thought, that none of us is going to live long enough to see evolution from the single cell to the vertebrate. But that is a pattern by which we can think. He said, "Now I hope no one will take me to task because I sat down and spun out, in my vision, this theory of evolution. Whether we prove it or not," he said, "does not make any difference, but it does help us to think." Now in seeing this correlation between soil fertility and nutrition, if we want to look at it that way, sometimes there is a cause and sometimes not a cause, from the soil to the microbe to the plant, and to the animal, with evolution working that far. Then man comes in at the top and stops the processes by what he does. It looks to me as though that large basic approach will be ever helpful. So we ought to say, "That is stimulative thinking and whether we prove it at all or not is a matter of no great concern," because after all, this struggle for food in fullest nutrition gets to be a real problem. I am concerned with emphasizing food. It must multiply the cells. It must protect them against consumption by foreign proteins—call them what you like, microbes, viruses or anything that might

digest them or be disease. Then it must support reproduction to keep the species going. Only protein foods can carry out these three functions.

In a lecture recently, Dr. Beadle of California pointed out that a change or a mutation is the one factor by which there is survival—that is fitting the species to a new situation, and that is basically a chemical fitting. So it is that larger pattern which seems to me to be challenging us, as Darwin's conception of evolution was a help in that direction. I do not want to make too much of this story of soil fertility and dairy cows, but I do want to say what I said yesterday. I had a contact with the idea that was begun as a test here. As Dr. Norman said, it was not an attempt to prove anything particularly, but it was the beginning of a *study*—not necessarily going to establish something and say this is it and nothing else, so help me God. But it was a start to learn what we can do at the starting point of the assembly line of chemical dynamics of agricultural production which is the soil. If we do not create wealth there, we certainly are not going to do much except convert our existing materials otherwise. So this study in soil fertility and milk quality is merely the beginning. As Dr. Beeson has said, "We see some interesting things in the data." I did not have contact with the data until yesterday, but I was interested in one aspect; namely, the manifestation that a high manganese content in the supposedly unfertilized soil carried over into the plant as high manganese there, and into the milk as high values there also. When we deal with the life struggle, we deal with limiting elements and in the manuscript which was prepared for this occasion one of the sub-titles is this, "The Limiting Element Limits More Than Itself." We tried to bring that idea out by showing the significance of calcium as a mobilizer of other nutrients. The interrelations of calcium and potassium, of calcium and magnesium, of potassium and nitrogen, and so on and so on.

Now, some interrelations are coming up in the trace elements. When we do experimental work with two variables, we have a tremendous task, three are still worse, but when we come up with many of them in the biology of the animal, it is a real job to put your finger on the control. And so we have a limiting element holding this activity down, and occasionally now and then you get one that creeps in above. I like the way Dr. Norman puts it, "Occasionally, we have a luxury consumption of one element because something else is limiting. When we boost that limiting one, then luxury consumption of the other one disappears." In agriculture we do not emphasize *luxury* consumption possibilities. We are on *poverty* consumption most of the time. We are making cheap milk, cheap fat; we are trying to skimp this biological mechanism all the time. That shortage shows itself as one question puts it here, "Why be concerned about the trace mineral or vitamin composition of food as long as the yield of calories is a maximum, since minerals and vitamins can be added to the ration?" Well, that means we are going to be content to get along on obesities—to which we listened so effectively this morning—excessive fats, the calorie concept of life, and "I'm not going to worry about the conditions of the stove in which to stoke the fuel" is major. When we must build a stove or body first from only the fuel we put through it, we are going to get along on "hidden hungers" until clinical disaster pulls us down. So instead of using prevention, we are continually going to be curing, patching up. We take the body for granted. When we deal with a biological performance that operates naturally under the 100 percent safety factor with two lungs and two kidneys when we can survive with but one, I'm afraid a lot of us are going to be limping along with one lung and one kidney before we recognize that the body is manifesting its deficiency symptoms. We hope you will leave the other questions, Mrs. Smith, in order to give some other folks their time.

MRS. SMITH: Since Dr. Albrecht has referred to the studies here at Michigan State, before we pass on to some of the human aspects of this I wonder if the folks from Michigan State have another word or so that they might like to say at this time.

Professor Duncan, would there be anything that you would like to say?

PROF. DUNCAN: I would personally hate to see you people leave this institution thinking that we had solved all the problems in connection with this nutrition experiment. We only had a few objectives, but a great many other problems came up in the course of the time that this work was carried on. We have not attempted to do all the soil problems or things like that, as the project has gone on. We aimed to raise the same type of crops on soils that were fertilized to the best of our ability. The other soil, of the same type, was depleted to the extent that the crops would hardly grow without the addition of nitrogen. We were interested in feeding those crops to two groups of cows to see what effect they had on the health, milk production and reproduction of the cattle. Those are the things in which we were primarily interested. In carrying out this project numerous other important problems came up, but we did not have the time, the money, or the personnel to carry the project any further. We hope others will carry on and enlarge this project in other parts of the country. That was one of the objectives in presenting this material at this time.

MRS. SMITH: Thank you Professor Duncan.

In coming to Michigan 10 years ago it was my treat to meet the people out here at Michigan State College and learn that they were working on this project. One of the first persons that I made contact with and talked to was Dr. Turk. Dr. Turk, I am sure that you would like to say something about what you probably call your first love.

DR. TURK: I have had occasion in the past several years to talk to several groups in regard to the broad subject of the interrelations of soils, plants, animals and humans. On numerous occasions I have been asked, "How do you reconcile your statements with those of Dr. Albrecht." Now Dr. Albrecht was my former boss and I had my graduate work under him. I have the highest regard for Dr. Albrecht's work and ideas and ability as a speaker and I have told these folks on every occasion that I think there is no fundamental conflict between the ideas we have expressed here in this project, and Dr. Albrecht's.

MRS. SMITH: Dr. Weaver, do you have a few words to say on this project?

DR. WEAVER: It is my particular responsibility to serve as chairman of the committee that has been administering this project. We are extremely gratified and we feel highly complimented by some of the words of commendation that we have heard from some of you and from some of the speakers. We have made apparently successful efforts to interrelate different fields—to coordinate the activities of workers in different fields in order to achieve some benefit from this project. The panel here will not, because they are gracious, be too critical, but let me assure all of you that when I get this committee together from time to time there is no lack of criticisms and study of the procedures we have used. We hope to remain pretty free with our criticisms. One of the first comments that was made was that the cow was probably not the most suitable animal to make this study. That has had our attention very definitely.

We have a committee meeting called in the Director's office for next Tuesday afternoon to ascertain, discuss, and contemplate the future of the project. As a personal favor, I am asking any one of you who has an idea to please convey it to some members of the committee as to the procedures we should take in carrying on this project, if we are to continue to carry it on. We may, then, criticize that we did not have the right animals, that we did not select the right crops or the right feeding. We shall criticize various aspects of the project. I have been worried and a little disappointed since the first year, when these cows failed to respond as I had anticipated. I am not a research worker—I am merely chairman of a committee of research workers. I am afraid that I must admit—with all respect to what was said by Dr. Norman—that this experiment was not started to prove a hypothesis—I am afraid that I had my own preconceived notions. Ladies and Gentlemen, I was not a research worker on this, and they, the research workers, were free of that bias. When I walked into that barn in 1947 I said, "Well, sisters, just wait till the next generation and you will come through. After we fertilize this area for 5 years and this other area has been neglected, you will start paying attention to the importance and tradition of good nutrition and I will be happy." And I am more happy today than I have been previously. The last few days have been most refreshing to me. I think our bovine females and Dr. Cederquist's male rats and Dr. Albrecht's crickets of both sexes have behaved normally.

I am going to ask if you would give us one vote of acclaim for what we have done. I am soliciting some self praise. Will you admit with me that we did one good thing when we started this project? We made lots of errors, but will you say we did one real good thing, that we made one particular effort and in that we were successful. We arranged that not one cow in that herd was ever permitted at anytime to read any of the popular or scientific literature on the subject.

MRS. SMITH: Dr. Beeson has something he wants to say.

DR. BEESON: I think that this is wonderful. I just want to keep the record clear. I did not say the cow is not the best animal for this experiment. I think the cow was the best animal for this experiment. I would say just one thing, and I think you will agree, that the cow is not the best or only animal to test the subtle differences in soil fertility.

DR. WEAVER: May I apologize if I intimated that we challenged that question of yours. Steve Dexter has said for over a year that we have got to change and get some non-ruminants in order to get results. So our committee itself has been very much concerned with your own viewpoint.

MRS. SMITH: Dr. Dexter, would you like to defend yourself?

DR. DEXTER: I feel that I can add comparatively little to what I said in my opening remarks. As some of you may not have heard the opening remarks, I repeat briefly. Whether we like the cow as an experimental animal or not is a matter of very little concern at the moment. There are, however, in this country something in the general neighborhood of 100,000,000 ruminant animals living on our farms. These 100,000,000 ruminant animals eat certainly a good deal more than

one-half of the feed that we produce. Experimentally speaking, it is perhaps unfortunate that the rats consume such a small percentage of our hay crop, pasture and what not. However, since these rats, guinea pigs or crickets are not concerned with eating this feed and the dairy cattle and ruminants are, I still would suggest, with Dr. Beeson, that for our purposes the use of ruminant animals was necessary and, as I said in my introductory remarks, I am afraid that the use of crickets would not have been found acceptable by the American Dairy Association. All these points were considered in detail before we started this problem. In fact, I believe the first year we wished off on the animal nutrition people the project of feeding these crops directly to non-ruminants. We did feed these crops to non-ruminants for a period. For at least the past two years, we have been considering what this nutrition project should include after the phase with dairy cattle was completed. I have been proposing that we might use all of our fertilized and all of our unfertilized land for growing feeds suitable for non-ruminants. Then we would be able to study the effects of such feeds on animals that are accepted as being more sensitive to minor (or major, if you like) and more subtle differences, as I discussed in my original paper.

I may say in connection with Dr. Weaver's discussions with the committee, that a great many things have come up in the course of these years. A great many side lines have been suggested. A few have been followed. The committee has been downright stubborn in persisting that we investigate the project that we started.

I believe that my defense—that we fed feeds suitable for ruminants to ruminants—is a valid defense.

MRS. SMITH: Thank you Dr. Dexter. Before I move on to humans I believe that we recognize that we are all greatly indebted to the cow. Dr. Huffman would you like to take a bow in thank you to the cows?

All of this food is important to us as human beings because as the fadists say, "We are what we eat."

Perhaps, Dr. Brozek, you would like to make a few remarks—since you did not have time to finish your speech.

DR. BROZEK: I was talking about distressing things—morbidity and mortality—and maybe I should end this discussion rather than come in the middle. Dr. Wells, would you cover these points?

DR. WELLS: I think in some of our discussions that we become so specialized that we forget to look at the whole picture. That is what I am trying to say. The only general comment that I have, Mrs. Smith, is this: In some of our endeavors to find out from our own particular standpoint and field of science what the all-important over-all nutrition problem is, we forget to look at the whole picture. Where I stand in Washington I don't know what the Big 4 of nutrition is; whether obesity is the worst curse, whether dental caries is the worst curse, whether cancer is the worst threat, or whether nervous tension is the worst threat. All of these I am told in varying degrees are likely to kill us off. If you can live long enough you are likely to get most of them. Now in our dealings with this whole field of nutrition, we are liable to forget the main point when we are talking about our own specialized interest. The first job in nutrition and the major job of the people working with nutrition is to maintain a suitable level of nutrition for the people in the United States. We should try to get the maximum preventive effects that we can get from good nutrition and then having done that, we may get interested in these specialized fields and try and follow them down and find out which is the most important.

DR. BROZEK: As I said, I hate to talk about morbidity and mortality. So first I will answer a question that is addressed to Dr. Darby, a question that is more interesting anyway. The question is "In countries where the level of protein in the diet is low have you found, Dr. Darby, that the human birth rate was low?" The facts would answer the question negatively. The question of birth rate is a very complex one involving endocrinology, sociology and psychology but the answer would be negative. In other words, in countries or regions of low protein consumption the fertility rate is not necessarily and not usually low. Would someone else like to say anything on this question.

MRS. SMITH: I asked Dr. Brozek to answer this question purposely because I know the work that they are doing at Minnesota is probably concerned with vital statistics as much as any group engaged in nutritional research. But we would be very glad to hear from anyone else in the audience who would like to contribute to this question. Dr. Brozek, do you have another question?

DR. BROZEK: Yes, there is another question by Dr. Prince. "Is there any connection between the hereditary characteristics and incidence of heart disease?" One question mentions the Japanese and Africans. I have mentioned and I hope I made it quite clear that we are dealing with a very complex situation and our present understanding is far from being complete. Hereditary factors are widely present in the development and incidence of heart disease but we do not understand the mechanisms nor are we able to portray the relationship quantitatively. We need more

facts. In this case those facts can be obtained by comparing the incidence of degenerative heart disease in the African and Japanese maintained on diets other than those which are eaten either in South Africa or Japan. I do not have the figures on the Japanese in this country, but this is the group that will answer the question whether this matter is genetic "racial" or not. Actually, this would be a matter of degree anyhow, because we do have some evidence from other regions, from Italy, and Spain, where Dr. Keyes was doing field work. There, in the same region, in groups that are genetically as comparable as you can find, the incidence of arteriosclerosis and other diseases related to it are different in the different socio-economic groups, and consequently in different dietary groups. Thus in Madrid in people living on low fat diets the blood cholesterol and also the incidence of coronary disease was low. Whereas, in the group of professional people—and here specifically the doctors and physicians, who are paid very well indeed and have a high fat intake, there was the same incidence of coronary complications, and more important the level of blood cholesterol was much the same as in Minnesota. Consequently, where we do have data we can show that it is the diet which is the principal differential factor even though in individual cases heredity cannot be neglected.

We have been talking about population groups and I would like to stress this once more. We are dealing with averages, not with trends. Within each of these groups there will be individual differences—differences in the way in which they are able to handle fats. Let's be careful with our generalizations. We are just at the beginning. The general pattern that we see from population comparisons points to interesting and important relationships. But we would be the last to say that this is the last word, and that diet is the sole factor in the development of arteriosclerosis.

MRS. SMITH: Thank you for the warnings.

It has been said that this country is a land of plenty but we appreciate that this plenty is not evenly distributed. I am sure that the industry that preserves food has helped to make this a land of plenty. I am wondering if Dr. Clifcorn has come comments that he would like to make, which he did not make yesterday, and then perhaps answer the questions that have been directed to him.

DR. CLIFCORN: I think that I overdid my subject yesterday. I took too much time, but I tried to stick to the subject that was assigned to me. I am sure that I could have made a more interesting talk if we would have had the subject, "Where Are We Now and Where Are We Going?" Nevertheless, I have a license here, a fisherman's license from the state of Ilinois, that allows me to comment generally on the things that have been stated in this very excellent symposium.

First, I am going to strike at some points, and I don't know whether they are going to be agreed with by many of the people here at this meeting, but let us look at the facts. In meeting the nutrition levels of the people of the United States, we have areas of production and we have areas of consumption. In our milk areas— and this has been very much a dairy and milk symposium but justifiably so—there are lots of problems and lots of things to be done. But when you get down into Arkansas, will you tell me why we have been so stationary in using new techniques that we have plainly before us and still have to ship truckloads of milk to Arkansas from my neighborhood, Berrington, Illinois? Will you also tell me why with available methods to get the milk down in the better and cheaper fashion, the dairy industry persists in shipping all the way from Minnesota by tank truck down to Houston, Texas at two dollars per hundred more than it sells for in the state of Minnesota? What I am getting at is that it seems to me, Dr. Wells, from the standpoint of having the pleasure of sitting with you and participating in this symposium, and likewise being very close to the people who are in Washington in the milk processing end of this, that we should begin to stick the needle into this intermediate area of putting milk into some kind of container —it need not be tin, it can be paper with some kind of a good solid protective barrier on it— and instead of hauling it in tank cars, let us load it on freight cars and more lesiurely and more cheaply get it to the areas of consumption. By so doing we are going to be able to deliver milk cheaper, and we are going to get more milk consumption because today all people cannot afford to buy all the milk they need for their large families. We will be able to cut down materially on this high five-cent-per-quart cost of getting the milk from the farm to the consumer. We have know-how presently available as to how to do this.

Pasteurization times and temperatures have been based on the vegetative bacteria, pathogens, and so forth. Not much needs to be done with that time-temperature relationship to produce a sterile milk. I don't know how many times I have said over the last five years to dairy people, "Why not put it into a sterile barrel—the know-how is there—and very casually wheel it into cars. And if you want to save space and save weight, which is truly an army and navy problem, we can make square containers of any composition,

and aseptically treat them on the inside, run this milk in and ship it down so that it will get there at a moderate cost for delivery." That is the one thing I can not understand, and I have been a little emphatic about it since leaving some men I have thought very highly of in the dairy field, Professor Hart, Stephen Moulton Babcock and others at the University of Wisconsin whose hearts were in this milk problem. Seeing this large gap in the middle has disturbed me very much. We have done a lot of work on it in our own organization and we are sponsoring work on it at a university. We have tried to make a better beverage of milk in containers with a shelf-life that will be long enough to meet the demand. Currently you can do it and have a 60-day storage-life of fresh milk. As Gobel would say, "So there you are."

MRS. SMITH: Thank you very much. Dr. Albrecht has some questions which he has not had an opportunity to answer. We promised the panel and the audience that we would adjourn on time.

DR. WELLS: I have two questions here.

Question 1. "What is the USDA doing to supplement its food or farm planning activities with *food constituent* economics?"

I take it this question really has to do with the relative cost from various sources of the basic nutritional elements in our food. For example, I happen to have before me a little pamphlet put out by an Economic Research Bureau which indicates that the cheapest form of protein which American consumers can buy today in the retail store is, of course, dried skim milk or non-fat dry milk solids.

We have done a considerable amount of work in this field but we have never been willing to assume that American consumers are interested only in adding up the chemical or nutritional elements of their diet at the lowest possible cost. Our Human Nutrition and Home Economics researchers have generally been inclined to talk in terms of four levels of diet—that is, they have worked out suggested or recommended diets whose costs are related to four different income levels, ranging from a restricted low-cost diet to what most of us would consider a very liberal diet. But in doing this work our nutritionists and economists are concerned not only with getting adequate nutrition at reasonable cost, income-wise, but have been equally interested in suggesting or working out diets which take into account the food habits and preferences of the people involved.

Question 2. "Would you care to comment on the "Unimal" that Purdue University is sponsoring or using in connection with the National Institute of Animal Agriculture?"

For those of you who don't happen to be familiar with it, the "Unimal" is our old farm management friend or standard feed-consuming measure—the animal unit—dressed up by an imaginative mind with the cooperation of a good commercial artist. The animal-unit idea originated among farm management researchers who wanted some means of adding the feed-consuming demands of cattle, hogs, poultry, and sheep together. Not very long ago one of our farm cooperative leaders who also happened to be a regent at Cornell University, Dr. H. E. Babcock, got together with an artist and developed a composite picture of an animal unit which they labeled the "Unimal." At first glance this creature resembles a good beef steer but you are also aware at the same time that it has wings and some other aspects that remind one of a pleasant platter of fried chicken, that it has the fleece of a sheep, the udder of a dairy cow, and a conformation and certain other characteristics that suggest bacon and ham. Purdue University has used this as a symbol of its National Institute of Animal Agriculture which is an annual meeting at which scientists and economists are asked to discuss the problems relating to better nutrition and better agriculture, with especial emphasis upon the place of animals and grasslands in such a development.

MRS. SMITH: Perhaps this is the answer partly to this question which was not directed to any particular person on the panel. Here is the question: "We have heard interesting presentations concerning protein content of feed and food but no discussion of possible new or currently unused sources of protein that would be much more efficient than our current protein production." I am not sure that it would qualify in this later category of efficient production but at least your reference to the non-fat solids and the animal may be the partial answer to this. If we have time we will come back to this. I would like Dr. Albrecht to have time to answer the question before him.

DR. ALBRECHT: Thank you, Mrs. Smith: I am stimulated to participate in this activity. It is one of the most stimulative performances we have had happen among land-grant colleges. I have a feeling that the reaction among other colleagues to what is going on here is one of the best signs that some challenging thinking and interesting work is underway here. One of the ways a teacher in a college or university can tell if he is keeping interest and attention is to consider the questions that are asked. The question is "What evidences that are available show that a high carbohydrate, low protein diet reduces reproductive efficiencies in animals?" We shall not go forward to answer

the others about man, because I shall limit discussion here to animals.

In some trials, using the rabbits, and giving them the corn with a constant hay supplement, we cracked the corn. In one set of rabbits, we took the corn away and gave them a new allotment when they had eaten 25 percent of it. In another, we did not take the corn away until they had eaten 50 percent, and in the third lot, 75 percent. As a result of the rabbits' choice, they increased the protein content in what they consumed by 12 percent when they had only 25 percent. They enriched their ration by selecting more of the germ, and less of the endosperm. Where they were compelled to eat 50 percent, they selected 6 and a fraction percent more protein than the corn contained as a whole. In the other case, their selection enriched the ration by only 3 percent. In the limited hay allotment, which was very low in relation to the corn, it didn't take very long to find sexual indifference of both male and female on the third ration before we had it on the other two. If you increase the hay, red clover in this case, the period is longer before you get sexual indifference. So, by evidence of that kind, it looks as though even the animal's choice comes into play to improve sexual efficiency. When we made those animals—they were not weanling rabbits—consume 75 percent, they gained more weight per unit of feed consumption, but we bought that gain in weight at depreciation in the instinct of reproduction. So the animal, at least the rabbit, does not choose to be fattened. It has other ambitions.

Now, relative to the next question, may I recall again the high concentration of manganese of the unfertilized soil, which carried through the crop to the milk, but not so much so in the case of the lower manganese of the fertilized soil. This seems to be the exception in the data that proves the rule. When we moved into fighting soil acidity, we disturbed our thinking seriously. When we neutralize the soil with lime, we are apt to run into some more problems, especially about manganese. Now for the next question asked, "Was the dwarf calf in the last slide of the lecture caused by inadequate or improper nutrition of its dam? If so, how do you explain, first, the fact that twin calves had been born, one of which was dwarf, and the other normal; and second, the fact that dwarfism occurs more frequently in Herefords and Angus, than in the Shorthorns?" We have also had that happen in the litters when the hog was involved. I am not familiar with the factors and variables in this respect, i.e., the fact that in large herds, some bulls sire dwarf calves, and others do not. Well, I wish I could say.

There is an interesting suggestion for theoretical consideration in this. There is the fact that, as far as I have been able to learn, this ailment has come in particularly on the western edges on highly calcareous soils of the mid-continent. Then a few scattered cases are creeping in on the eastern edge, where it is interesting to correlate the fact that those are on soils that have been highly limed. Our highly calcareous soils, as we go farther west, are a different nutritional story than our eastern soils. There is a relation suggested between calcium and one or two of the other elements that would be a very good basis for some theoretical consideration as experiments, but I doubt whether we are quite in a position to start too far into it experimentally without some additional observations. However, it looks very much as though it is one of those imbalances that occurs in nature when we push the cattle off onto the fringes, and particularly to a one-crop diet, as is true in these states with which I am familiar with incidents of dwarfism and soil conditions. It may be a case of putting too much faith in alfalfa, if I dare put it that way, and alfalfa alone, a highly calcareous proteinaceous substance. In this dwarfism, we have some suggestion that our "fighting soil acidity," an implicit faith in neutral soils and animals pushed on to those soil fringes may be the significant factors involved.

Now the next question was about the cat experiment. My part in the cat experiment was not the experimental part. The experimental part of what those cats did on evaporated milk and raw milk, as reproducers, as mother cats, as developers of bodies—which can be seen from the X-ray bone pictures—is reported in the Journal of Oral Surgery, published in St. Louis, as reported by Dr. Francis M. Pottenger, Jr. He is an M.D., with a hope, and success in feeding children. He has about 40 on his premises or in his hospital most of the time—with good nutrition as a source of good health. He investigated this matter of cooked and pasteurized milk. He used cats as test means in his experiment. My part was merely observation of the pens after the cats had been in them two years, and the interpretation of the effects of the buried cat dung on the volunteer weed crops and planted bean crops.

The volunteer weed crop was my first observation and then what happened to the bean crop challenge of such an observation, because there afterwards. I am very much interested in the we had a very delicate change in body form from a dwarf bean plant to a vine-producing plant, suggesting that we have a substance, a plant hormone, failing to be formed, associated with the indole-cycle in the dwarf bean plants in which there were the boiled milks in the buried dung,

while we had something radically different in the raw milk—nothing added, nothing taken away, just some different temperatures involved in the milk treatment. What we reported was not an experiment, but an observation, and a challenging one, in my humble opinion, when the indole-ring compound seems to be so basic. We discard indole in our digestion when we knock off the amino propionic acid in tryptophane digestion, and use that part only. Then it looks as though the plant took up all the indole and, in the case of the raw milk going into buried dung, the plant was able, at least with the bacterial help in the soil, probably, as a theoretical consideration, to synthesize the indoleacetic acid, if that is the hormone built out of the indole, and stimulate that crop to grow into a vine bean in the place of a dwarf bean plant. Our botanists and plant physiologists are telling us that indoleacetic acid used to be called "auxin." There was an indole odor in the bean seeds grown in the pens where heated milks were the cat diet. I was stimulated very recently to listen to Dr. Beadle, whom I have quoted before, telling us that one of the first basic reactions in getting the gene formed is the closing up of the indole ring from a carbon chain, or getting it into what looks like the indole ring.

In our experimental work, we varied calcium and potassium, one a divalent and one a monovalent cation. We varied also the nitrogen, a monovalent anion and sulphate, a divalent anion and phosphorous, a trivalent anion, all basic soil consituents—when we grew brome grass. We analyzed the crop for twelve amino acids, including tryptophane and four carbohydrates. We could vary any one of those five ions in the soil, and we had a resulting variation in each one of the four carbohydrates, and each one of the twelve amino acids. While the amino acids fluctuated up and down in total and in relation to each other, there was one very definite suggestion: namely, that tryptophane, being very low, was related more definitely to many of the rest of them, particularly to those that are commonly low. It looks as though we are dealing with tryptophane as a limiting compound for production of the others among that list, even of those amino acids. Probably in that trypophane, we are dealing with something that starts far back, perhaps as far as a gene, and is right at the very door where life is taking off on what we expect of it. Now, that may be excessively theoretical thinking, but it looks to me as though that is what these meetings are for—to set ourselves off in a long vision, but well-anchored to something that looks as though it might be basic, and when we start with the splitting of a cell and expect it to reproduce, it always must grow back to volume. We cannot just divide chromosomes and genes forever, and not run out of them. It looks as though we occasionally cut one off and never get it back again, and that is probably our mutation. It looks as though in the creation of this tryptophane and this indole ring, we may have a troublesome job for the plant to accomplish, particularly when indole rings of all kinds are so significant in small amounts, as we discover when we scatter 2,4-D, benzene hexachloride, and some other similar rings of poisonous nature around. We are now getting around to where some of these items are becoming very delicate in amounts representing damage.

While speaking about the plant and its metabolism, we had a high temperature of 113° F. kill the enzymes in the leaves of our corn this summer. That stopped synthesis of nitrogen into protein in the leaves, but it did not stop the accumulation of nitrate in the soil and also in the plants. We measured accumulation and greater concentrations within the sections of the stalk nearer the soil. So when the cattle were turned in fields all over the state of Missouri to eat that corn as foliage about September, reports came in that 200 head of cattle had been killed, because they had eaten that foliage so high in nitrate. It gave the suggestions of a nitrite and nitrate poisoning. We had it with babies, too, in Kansas, in 1948, out of midwestern Kansas where the dry winter and the late spring rains put high nitrate from the soil into the well water of shallow wells. Dr. Miller of Kansas City was successful in rescuing one of those babies after the preceding two failed to get to Kansas City. In the Kansas City Star, Easter Sunday issue of 1948, I think it was, you may have read the story of the literal resurrection of one of those little babies, because Dr. Miller was able to get methylene blue into the blood stream just at the crucial moment.

Well, these questions merely suggest that when we are dealing with factors as numerous as those that represent higher life, we are dealing with an integration, and not an addition of their effects. When we are dealing with multiplications, permutations, and combinations, to think that we can put our thumb on a single control, is a rather ambitious assumption, which I hope we shall establish to our satisfaction as time goes on. Much more study and experiments must precede that accomplishment.

MRS. SMITH: There is one more question that we are not going to discuss, but I think I should read it because it takes in the broad scope of interest in this audience. The question was addressed to Dr. Todhunter and is really the $64 question, I think, and would take another 2½-day symposium. Question: "In teaching and advising on food nutrition, how do you meet the problem of variation in

food acceptance and availability that lie in habits?" Perhaps you can measure the success of a meeting by whether you go away with all the questions answered or if you go away with more questions than you came with.

Dr. Clifcorn: "What are the problems, the successes and failures of radiation in preserving foods?" a question by Colonel Paul Howe.

I don't have time to discuss the question now as the time I have is overdue, but I would like to have luncheon at the same table with Colonel Howe and any others who are interested in this subject so that we could discuss it during the lunch hour.

Dr. Zoe Anderson: I would like to thank the staff members of Michigan State College in behalf of the American Dairy Industry, the American Dairy Association and the National Dairy Council, especially those who worked actively, and the visitors who took part in the symposium for their cooperation. I want to say that the future of all food industry is going to be greatly affected by what is done in the agricultural colleges in the field of nutrition and in the agricultural problems as they are investigated. The food industry is using this information that comes from the colleges for the purpose of basing their industry practices on the knowledge that has been obtained. We would like you to know that that is our interest in it. We are not just looking for something that will help us sell our product. We are also looking for information that will help the food industry do a better job of feeding the American people. Thank you.

Dr. Turk: It was the feeling of the committee in arranging this program that we would not be interested in having people of second order—that we wished to obtain the top people of the country to participate in the symposium. Of course there are others as well—we couldn't have all the top people—but I think we all agree that these folks have done a splendid job. They have presented their material well. Their slides have been well prepared and of such a nature that they could be seen, and I certainly appreciate the cooperation of all the members of our staff. Certainly the attendance has been beyond our expectations. We have folks in attendance here today from the West Coast, several from Canada, from Alabama, New York State and Venezuela and I am sincere when I say that I haven't attended a conference where the audience was more attentive.